

Field Investigation Plan

Pike Hill Copper Mine Corinth, Vermont

Remedial Design
EPA Task Order No. 0111-RICO-017J

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Region 1
5 Post Office Square, Suite 100
Boston, Massachusetts 02109-3919



Nobis Group

Lowell, Massachusetts
Concord, New Hampshire

Phone (800) 394-4182
www.nobis-group.com



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AC ACRONYMS AND ABBREVIATIONS

ABA	acid-base accounting
ABS	dermal absorption factors
ADD	average daily dose
AF	adherence factor
AEi	assimilation efficiency of the ith food item
ARD	acid-rock drainage
ARAR	applicable or relevant and appropriate requirements
ASTM	American Society for Testing and Materials
ATV	all-terrain vehicle
BERA	Baseline Ecological Risk Assessment
bgs	below ground surface
BOM	U.S. Bureau of Mines
BW	body weight
CAL	three-arm caliper
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CGP	Construction General Permit
Ci	concentration in the ith prey item
COC	contaminants of concern
COPC	chemical of potential concern
COPEC	chemicals of potential ecological concern
Csed	concentration in sediment
CSM	Conceptual Site Model
CTE	central tendency exposure
Cw	concentration in water
DO	dissolved oxygen

DPT	direct push technology
DQO	data quality objective
EA	exposure area
ED	exposure duration
EEL	estimated exposure level
EF	exposure frequency
EM	electromagnetic
EPA	United States Environmental Protection Agency
ER	Electrical resistivity
FI	Fraction Ingested
FIP	Field Investigation Plan
FIR	body weight normalized food intake rate
FMEA	Failure Mode and Effects Analysis
FMR	free metabolic rate
FS	Feasibility Study
FSP	Field Sampling Plan
FT	foraging time
FT/FR	fluid temperature and fluid resistivity
GE _i	gross energy of the <i>i</i> th food item
GIS	geographical information system
GPS	global positioning system
GRA	General Response Action
HASB	hand-auger soil boring
HEAST	Health Effects Assessment Summary Tables (EPA, 1997)
HHRA	Human Health Risk Assessment
HPFM	heat-pulse flow meter
HQ	hazard quotient
HSA	hollow stem augers
IBVA	in vitro bioaccessibility assays
IEUBK	integrated exposure uptake biokinetic

IRF	fish ingestion rate
IRS	incidental soil ingestion rate
IRW	groundwater ingestion rate
LiDAR	Light Detection and Ranging
LADD	lifetime average daily dose
MCL	Maximum Contaminant Level
mg/Kg	milligrams per kilogram
mg/L	milligrams per liter
MIW	mining impacted water
mm	millimeters
MSL	mean sea level
mV	millivolts
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
Nobis	Nobis Group
NPL	National Priorities List
NR	normal resistivity
NRWQC	National Recommended Water Quality Criteria
NTCRA	Non-Time Critical Removal Action
OEME	Office of Environmental Management and Evaluation
OU	Operable Unit
ORP	oxidation-reduction potential
OSHA	Occupational Safety and Health Administration
OTV	optical televiewer
PAH	polycyclic aromatic hydrocarbons
PAL	Public Archaeology Laboratory
PCB	polychlorinated biphenyl
PDI	Pre-Design Investigation
PEC	Probable Effects Concentration
PEF	particulate emission factor
PHB	Pike Hill Brook

Pi	proportion of the ith prey item in the diet
PID	photoionization detector
PVC	polyvinyl chloride
QA	quality assurance
QAPP	Quality Assurance Project Plan
RAO	remedial action objectives
RBC	risk-based concentration
RD	Remedial Design
RI	Remedial Investigation
RME	reasonable maximum exposure
ROD	Record of Decision
RPN	FMEA risk prioritization number
RQD	rock quality designation
RSLs	Regional Screening Levels
SA	surface area
SAP	Sampling and Analysis Plan
SARA	Superfund Amendments and Reauthorization Act
SIR	sediment ingestion rate
Site	Pike Hill Copper Mine Site
SLERA	Screening Level Ecological Risk Assessment
SOW	scope of work
SP	spontaneous Potential
SPR	single-point resistance
SPT	standard penetration test
SSG	Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites
SVOC	semivolatile organic compound
TAL	Target Analyte List
TDI	Total daily intake
TOC	total organic carbon

TRV	toxicity reference value
µg/L	micrograms per liter
µg/Kg	micrograms per kilogram
UCL	upper confidence limit
URS	URS Corporation
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VOC	volatile organic compound
VTDEC	Vermont Department of Environmental Conservation
WIR	water ingestion rate
XRF	X-ray fluorescence spectrometry

1.0 INTRODUCTION

This Section describes the work scope and objectives and general organization of this Remedial Investigation (RI) Field Investigation Plan (FIP).

1.1 Work Scope and Objective

This FIP was prepared by Nobis Group (Nobis) for the United States Environmental Protection Agency (EPA) under Contract Number EP-S1-06-03, Task Order Number 0111-RICO-017J (Task Order). The work was performed in accordance with the August 5, 2016 EPA Statement of Work (SOW).

The Task Order SOW includes the completion of an RI for the Pike Hill Copper Mine Superfund Site (also referred to as the Site) located in Corinth, Vermont. The information to be gathered will be used to prepare an RI report, assess human health and ecological risks, and develop a subsequent Feasibility Study (FS) to develop a range of remedial alternatives to eliminate, reduce, or control risks to human health and the environment that may result from exposure to Site-related contamination.

1.2 FIP Organization

The FIP is organized as follows:

- Section 1.0 Introduction provides an overview of Task objectives and SOW.
- Section 2.0 Site Description and Setting provides a general description of the Site, including Site background and history, previous investigations, and general physical/geological information.
- Section 3.0 Previous Site Investigations and Data Collection Activities summarizes the previous investigations performed at the Site and at other Vermont copper mine superfund sites (Elizabeth Mine and Ely Mine).

- Section 4.0 Preliminary Conceptual Model presents the current understanding of Site conditions and describes migration pathways, fluxes, and reservoirs of contaminants.
- Section 5.0 Human Health and Ecological Risk Assessment describes the basis and assumptions for Site risk assessments and presents exposure pathway analyses for these assessments.
- Section 6.0 Preliminary Response Action Objectives describes the recommended approach to achieve project quality objectives.
- Section 7.0 Potential Remedial Alternatives provides a preliminary overview of remedial alternatives amenable to the Site.
- Section 8.0 Data Gaps Summary presents the supplemental data requirements to complete the RI and support the FS.
- Section 9.0 Preliminary Data Requirements presents the data collection activities that are planned to complete the data gaps identified.
- Section 10.0 Site Management, Access, and Sequencing of Activities outlines the general sequence of the RI activities.
- Section 11.0 References lists the principal references relied upon to establish the current understanding of the Site.

2.0 SITE DESCRIPTION AND SETTING

This section provides a brief description of the Site, its general surroundings, pertinent historical facts regarding the mining history, and an overview of the areal geology and hydrology as a context for subsequent sections discussing Site details.

2.1 Site Description

The Site is located in the Town of Corinth, Orange County, Vermont (see Figure 2-1). It includes the Union, Eureka (also known as Corinth), and Smith (also known as Bicknell) mines. The entire Site encompasses about 216 acres and contains approximately 20,000 tons of waste rock and tailings piles that are estimated to contain an average of 1.6 percent copper (USGS, 2006; PAL, 2011).

The Eureka and Union Mines are located approximately 300 meters apart near the top and northeast slope of Pike Hill and the two mines are generally considered to be a single-impacted landscape within the Pike Hill Brook (PHB) watershed containing a barren area of waste rock, tailings piles, open mine cuts, trenches, and mine shafts and adits (some collapsed).

The Smith Mine is located approximately 0.4 miles south of the peak of Pike Hill on the southern flank of the hill. It consists of three small mine waste piles and a collapsed adit that lie within the Cookville Brook watershed.

The Site landscape is a combination of barren open areas and patches of birch and evergreen trees. The locations of remnant foundations of an ore cobbing house, a blacksmith shop, the flotation/magnetic separation mill, and other features associated with historic mining operations have been documented at the Site (PAL, 2011).

PHB, Cookville Brook and their tributaries are the primary streams draining the Site, which eventually join the Waits River. Four significant wetland areas exist along PHB downstream of the Site. In addition, a small wetland exists along the tributary to Cookville Brook just upstream of the confluence with Cookville Brook.

2.1.1 Topography

A Site sketch is provided as Figure 2-2. Site topography is dominated by the north-south trending ridge of Pike Hill, which has a peak elevation of approximately 1,965 feet above mean sea level (MSL). The Eureka and Union Mines occupy an area extending from the peak northward and eastward along the eastern flank of Pike Hill within an east-trending valley defined by moderate to steep slopes. There is approximately 500 feet of relief between the top of Pike Hill and confluence of the tributary with PHB at the eastern margin of the Site at Richardson Road, below which the valley and PHB trend southeasterly. The Smith Mine is located on the east facing, moderate to steep slope at the southern end of the Pike Hill ridge. The ridge defines the western portion of a south facing valley drained by a tributary to Cookville Brook.

2.1.2 Population and Land Use

The Town of Corinth has a population of approximately 1,400 people (U.S. Census Bureau, 2012). The Site itself is located in a rural, sparsely populated area of the town accessed by Copper Mine and Richardson Roads. It is estimated that less than 100 people live within a one-mile radius of the Site. The nearest residents are located on the southwest side of Richardson Road, on the adjacent parcel southeast of the Site. The next closest residence is located northeast of Richardson Road. Six private water supply wells were identified within one mile of the Site, according to Vermont Agency of Natural Resources (VTANR) records (VTANR, 2017). Private wells identified in VTANR records are depicted in Figure 2-3.

The Site and vicinity are forested, with the exception of open areas occupied by mine waste rock or tailings piles. There are no residents or buildings at the Site. The Site is currently privately owned and has been generally undeveloped, unoccupied, and idle since cessation of mining activities. However, it is reportedly frequented by off-road recreational vehicles, hikers, and spelunkers and there is evidence of some disturbance to parts of the Site related to these activities, particularly within the underground workings that can be readily accessed in the winter when the mine pools are frozen.

2.2 Pike Hill Copper Mines

The Pike Hill mines include three separate mine workings (Figure 2-2) discovered in 1845. It is part of an associated group of ore bodies called the Vermont Copper Belt that also includes the Elizabeth and Ely copper mines (see Figure 2-4).

The Pike Hill mines are referred to, from north to south, as the Union, Eureka (a.k.a. Corinth), and Smith (a.k.a. Bicknell) Mines. The Smith Mine was significantly smaller than the other two mines. The three mines operated intermittently between 1846 and 1919, producing approximately 5,000 tons of copper, which comprised about 7 percent of the known production from the Vermont Copper Belt (PAL, 2011).

Copper ore was initially discovered in the vicinity of the Smith Mine on Pike Hill in 1845. Due to the low profitability of the Smith Mine, prospecting extended north as evidenced by a series of shallow trenches dug along the south side of the Pike Hill summit. In about 1853, mining of the Eureka deposit began at the peak of Pike Hill. Underground operations at the Eureka and Union Mines began in 1863. The ore mined initially was hand-cobbed and shipped off-site for processing at east coast smelters. In 1879, the ore processing plant was upgraded to enhance ore separation and ore shipment to the Ely Mine smelter until 1905. No smelting took place at the Site. In 1881, the known portion of the ore body at the Union Mine was exhausted. Between 1882 and 1916,

activities associated with the mines are poorly documented and appear to be sporadic (PAL, 2011).

From 1904 to 1907, Eureka Mine operations included an on-site processing mill which was used to experiment with separation processes, including magnetic separation of pyrrhotite, Wetherill separators, and froth flotation. Unlike the other mines of the Vermont Copper Belt, magnetic ore separation proved successful and continued for a short period (1906-1907) until the Eureka Mine closed temporarily in 1907. The Smith Mine had closed in 1882 due to low copper prices, but renewed exploration in the area occurred briefly in 1907 and 1908 and again in 1913 before being abandoned, leaving a relatively small area of waste rock piles and underground workings. The Eureka Mine ore mill closed in 1907 and activities are poorly documented between 1907 and 1915, suggesting limited mining. Operations at the Eureka and Union Mines resumed under a single company (Pike Hill Mines Company) between 1916 and 1919, when approximately 842,000 pounds of copper were produced using flotation processes with pine oil as an additive (PAL, 2011).

Operations at the Pike Hill Mines ceased in 1919 but were revisited after 1942 when the Vermont Copper Company, the owner of nearby Elizabeth Mine, purchased the property. The underground workings were never reopened, but during the late 1940s and early 1950s, portions of the ore dumps were trucked to the Elizabeth Mine mill for processing. The United States Bureau of Mines (BOM) completed several borings, conducted surface mapping, and compiled geological information in 1944 documenting the known extent of underground workings and interpreting the nature and extent of the ore body (White and Eric, 1944; PAL, 2011). Remaining Site buildings were destroyed by fire in 1960. Pat Mines, Inc. (a.k.a. North Gate Exploration) purchased the property in 1962 and owned the property through 1983 (PAL, 2011). The Site properties are privately owned and contain remnant waste rock/tailings piles, open cuts in bedrock, and abandoned underground workings, some of which are flooded. This Site

is eligible for the National Register of Historic Places due to its historical mining features (PAL, 2011).

The Site was placed on the EPA National Priorities List (NPL) in July 2004 due to the downstream impacts from acid rock drainage (ARD), posing a risk to fisheries in the Waits River and Connecticut River, as well as potential impacts to bats and/or persons who frequent the Site area.

2.3 Vermont Copper Belt

The Vermont Copper Belt, also known as the Orange County copper district, lies within the Connecticut River watershed in Orange County, Vermont, within a 20-mile-long north-south trending zone, as shown in Figure 2-4. It is reported to have supplied the largest historic metal production in New England from the late 1700s to 1958, primarily from the Elizabeth, Ely, and Pike Hill Mines. Other smaller deposits (the Cookeville, Orange and Gove Deposits) also occur within this belt. The ore bodies are stratiform massive sulfide deposits similar to those of the Besshi deposits in Japan and are believed to have formed as syngenetic-exhalative processes on the sea floor during the Silurian-Devonian age. The primary ore minerals include pyrrhotite, chalcopyrite with minor sphalerite and pyrite (Slack et al., 2001). The Elizabeth and Ely Mines lie within the Devonian Gile Mountain Formation, and the Pike Hill Mines lie within the Silurian Waits River Formation. The Elizabeth Mine and Ely Mine are described in further detail below.

2.3.1 Elizabeth Copper Mine

The Elizabeth Mine is the oldest and largest of the three primary mines in the belt, located on Copperas Hill in the towns of South Strafford and Thetford, Vermont. It was discovered in 1793 with mineral production beginning in 1809. The deposit was mined until the early 1880s for pyrrhotite to produce copperas. From the 1830s until the mine

closed in 1958, copper was mined from chalcopyrite in the deposit. Copper smelting occurred sporadically from 1830 to 1919. The mine was revived during World War II until it finally closed in 1958. The total copper output of the mine is estimated at 50,000 tons. The history of the mine spans approximately 160 years and included ore milling and smelting. The Ely Copper Mine includes the only intact historic metal mine process buildings in New England (Kierstead, 2001).

Today, the mine encompasses approximately 970 acres in addition to the mine process buildings: the mine area consists of four areas of mine waste rock and tailings piles; three open cuts in bedrock, two of which are water-filled ponds; and approximately 8,000 linear feet of underground workings with limited openings into the mine (URS Corporation [URS], 2006a). The Elizabeth Mine Site was listed as a Superfund Site in June 2001 due to environmental impacts from ARD from the Site on the West Branch of the Ompompanoosuc River. The mine is also eligible for the National Register of Historic Places due to its historical aspects (Hathaway et al., 2001). Remedial actions are ongoing at the Elizabeth Mine Site, and results of studies completed to support evaluation and implementation of remedial alternatives at the mine will form the basis of comparison for future RI/FS at the Pike Hill Mine Site.

2.3.2 Ely Copper Mine

The Ely Copper Mine lies between the Elizabeth and Pike Hill Mines and is located on the south side of Dwight Hill in the town of Vershire, Vermont. The mine was active between the mid- 1850s until 1905. Mineralogy of the ore body was similar to that of the Elizabeth and Pike Hill Mines. Operations at the mine included a large 24-furnace smelter plant, which was at one time among the top ten copper producing operations, with an estimated total copper production of 20,000 tons. It was the only copper mine in Vermont that successfully produced refined ingot copper on a large scale (PAL, 2005).

The mine encompasses approximately 350 acres, including areas containing waste rock piles and tailings, ore roast beds, a slag pile, and over 3,000 linear feet of underground workings with limited openings into the flooded mine. No buildings remain at the mine. Remnant foundations, pads and stone walls, including a 1,400-foot-long smoke flue, demark the location of former mine-related structures including a former flotation mill and the smelter plant. In September 2001, the Ely Copper Mine was added to the Superfund listing due to ARD impacts to Ely Brook and Schoolhouse Brook. The mine is also eligible for the National Register of Historic Places due to its historical aspects (Hathaway et al., 2001). RI/FS documents have been completed and RODs are in place for three Operable Units (OUs) at Ely and remedial design (RD) is ongoing at the Ely mine (Nobis, 2011 and 2015).

2.4 Regional Hydrogeology

This section briefly describes the general geology and hydrology of the region encompassing the Site. An additional discussion of the Site hydrogeologic conceptual site model (CSM) is included in Section 4.0.

2.4.1 Overburden Geology

The region was glaciated during the most recent, Late-Wisconsinan ice advancement approximately 13,000 years ago (PAL, 2011). Outwash, glaciofluvial, and glaciolacustrine deposits were generated in the region as a result of the erosional processes caused by the advance and retreat of the glacier. The dominant overburden unit overlying bedrock in the region is glacial till. Significant glaciofluvial, glaciolacustrine, and recent alluvial deposits are likely to be present at lower elevations proximal to the major rivers, such as the Waits River. Small alluvial deposits derived from reworked natural and manmade soils at the Site are presumed to be located along the banks of tributary streams close to the Site. Soils in the vicinity of the Site are

described as primarily Tunbridge-Woodstock, Colrain, and Buckland stony to very stony sandy loams (U.S. Department of Agriculture [USDA], 2016).

In addition to natural soils, the Site includes large areas of man-made and disturbed soils resulting from historic mining activities, including numerous waste rock and tailings piles. These soil piles are delineated with other historical mining features (as identified in PAL, 2011) in Figure 2-2. Surface soils distal from these soil piles, over much of the Site, have likely also been disturbed resulting from the expansive historical activities associated with the Site.

2.4.2 Bedrock Geology

The Vermont Copper Belt lies within a group of Silurian-Devonian rocks comprising the western portion of the Connecticut Valley-Gaspe' Trough extending from Massachusetts to Quebec. Stratigraphic units in east-central Vermont include from older to younger, the Northfield Formation, Waits River Formation, Standing Pond Volcanics, and the Gile Mountain Formation (Slack et al., 2001). The deposit at Pike Hill lies within the Silurian age Waits River Formation. These rocks have been deformed during three stages of folding and amphibolite-grade metamorphism during the Devonian Acadian Orogeny.

The bedrock at the Site is exposed at many locations in the upper elevations of Pike Hill and is composed primarily of metasedimentary rock (calcareous pelite/schist) representing a carbonate-rich turbidite protolith, and minor mafic metavolcanic rocks (amphibolite). The main belt of Gile Mountain rocks lies to the east of the Waits River Formation and is comprised primarily of metamorphosed siliciclastic rocks (graphitic pelite and quartzose granofels) representing a quartz-rich turbidite protolith. The amphibolites of the Standing Pond Volcanics occur typically along the contact between the Waits River and Gile Mountain Formations, and locally within the uppermost Waits River Formation, representing a suite of primarily thin metabasalts. The variations in

the stratigraphic position of the Standing Pond Volcanics suggests that the contact between the Waits River and Gile Mountain Formations is time transgressive. Slack et al. (2001) have suggested that the amphibolites observed in drill cores at Pike Hill represent Standing Pond Volcanic facies.

2.4.3 Surficial Hydrology

Surface water flow at the Site is controlled by the relatively steep, upland topography as well as the overburden geology. The locations of the Union, Eureka, and Smith Mines and their associated waste rock piles span the crest and the northern and southern flanks of Pike Hill.

The Pike Hill ridgeline forms the divide between two adjacent watersheds: one draining from the Eureka and Union mines to PHB and the other draining from the Smith Mine to Cookville Brook. A small volume of Eureka waste rock, located along the crest of Pike Hill and along the watershed divide, lies within the Cookville Brook watershed area.

The Eureka and Union Mine areas are located in a broad but well-defined, northeast facing valley drained by a single tributary which forms a major portion of the headwaters to PHB. A second headwater tributary to PHB drains an area immediately to the north of the Union Mine area which is apparently not impacted by the mine waste areas. At least four ephemeral seeps have been identified within the Site that contribute flow to these tributaries (Figure 2-2). These two tributaries merge at the eastern margin of the Site along Richardson Road to form PHB.

PHB flows southeast from the Site. Approximately 3.5 kilometers (km) downstream from the Site, it enters a series of four wetlands encompassing 70 acres. PHB then continues eastward another 3 km to its confluence with the Waits River. Figure 2-5 depicts the wetland complex. The Waits River eventually flows into the Connecticut

River. Both of these rivers are used for recreational purposes and contain fisheries (USGS, 2006).

The Smith Mine is located on the southern flank of Pike Hill, within 500 feet of a tributary to Cookville Brook. This tributary originates approximately 1,000 feet upstream from the Smith Mine in an area where historic prospect trenches have been identified but where no other significant mining activities are known to have occurred. This tributary extends southward approximately 1.6 km to its confluence with Cookville Brook. A small wetland exists just upstream of the tributary's confluence with Cookville Brook. Cookville Brook flows southeastward approximately 4.5 km from this tributary to its confluence with the South Branch of the Waits River. The South Branch then joins the main branch of the Waits River approximately 8 km downstream.

3.0 PREVIOUS SITE INVESTIGATIONS AND DATA COLLECTION ACTIVITIES

Section 3.0 includes a summary of the existing Site data that is relevant for the RI. These data were obtained during previous investigations conducted at the Site by the EPA, USGS, and State of Vermont. The data will be used to develop the current Site CSM, define the nature and extent of Site contamination, and characterize the human health and ecological risks and impacts that result from this contamination.

3.1 Vermont Department of Environmental Conservation

In 1997, the Vermont Department of Environmental Conservation (VTDEC) completed an ecological study of macroinvertebrate and fish populations in surface waters downstream of the Site indicating significant impairment presumably resulting from acidic mine drainage from the Site (EPA, 2004). Data from this study was not available for review.

3.2 USGS

3.2.1 Geochemical Characterization (2006)

USGS performed waste rock characterization, including bulk geochemistry, mineralogy, acid base accounting (ABA), paste PH, and a modified field leach test (USGS, 2006). USGS collected eleven composite soil samples (<2 millimeter [mm] size material) using a 30-aliquot sample grid over separate areas of waste rock and tailings piles encompassing all waste source areas of the Site (Table 3-1; Figure 3-1). USGS analyzed additional discrete samples of efflorescent salts, precipitates and ferricrete from mine waste piles, seeps, mine pools, and adit discharge areas. Twelve sediment samples and 45 surface water samples were collected from the mine pools, seeps, and tributaries at the Site and at select off-site locations along PHB, including four background samples (Table 3-2; Figure 3-2 and Figure 3-3). Water analyses included a wide range of major and trace elements, inorganic parameters, and standard field

parameters. Sediment samples (<2 mm fraction) were collected as 30-aliquot sample composites and analyzed for mineralogy and bulk metal geochemistry (Table 3-3; Figure 3-2 and Figure 3-3).

USGS concluded that mine waste rock and tailings at the Site are similar to the Elizabeth and Ely mine wastes, and are acid generating with the potential to release metals to surface water. However, because the Waits River Formation contains significant amounts of calcite and more buffering capacity, impacts to surface water may be less severe.

3.2.2 Surface Water Hydrology and Quality Evaluation (2007)

USGS performed hydrologic and water quality monitoring of the surface water bodies associated with the Site, including: PHB and tributaries; Cookville Brook and tributary; and the Waits River between 2004 and 2005 (USGS, 2007a; USGS, 2007b). Monitoring data included physical, chemical, and biological data from 14 locations, with primary focus on PHB (Figure 3-3). Continuous stream flow and water quality information included the use of three gauging stations with analysis of surface water samples during four synoptic sampling events. Continuous monitoring parameters included stream flow, specific conductance, temperature, and pH. Surface water samples were analyzed for major ions and trace elements and the results demonstrated concentrations of aluminum, cadmium, copper, iron and zinc above the National Recommended Water Quality Criteria (NRWQC). Benthic macroinvertebrate samples were analyzed from 11 sites (Table 3-4; Figure 3-2 and Figure 3-3). Biological data suggested gradually improving conditions downstream of the Site, with an increase in abundance and richness of taxa correlated with decreasing concentrations of ARD. The report documents seasonal variations in stream conditions including during snow melt, spring rain events, and summer/fall low-flow periods and provides preliminary interpretations of the interaction of downstream wetlands along PHB with surface waters from the Site.

3.2.3 Aquatic Assessment (2013)

USGS (2012) performed an aquatic assessment to characterize and evaluate the toxicity of surface water, porewater, and sediment quality for water bodies potentially impacted by the Site. The study evaluated previous results and incorporated new data collected in 2007. The study included 17 stream locations, each divided into 100-meter sampling reaches, and ten wetland locations. Benthic invertebrates, macroinvertebrates, and fish samples were collected, a fish assemblage survey was conducted, and ten sediment cores were also collected and sampled within four wetlands along PHB.

The evaluation found that degradation of surface water quality is dominated by elevated copper, and to a lesser extent, cadmium. Localized degradation was also caused by aluminum, iron, and zinc. Sediment was less uniformly impacted, with copper causing most of the degradation. In general, the farthest downstream locations and background locations did not appear to have toxic effects. However, sediment from most of PHB and the tributary to Cookville Brook had uncertain toxicity and one location indicated severe toxicity.

3.3 Nobis Engineering, Inc.

Nobis Engineering, Inc. (now Nobis Group) produced a CSM Technical Memorandum (Nobis, 2008) summarizing the work conducted at the Site up to that point in time. The report also included a preliminary CSM regarding hydrogeology, contaminant sources and migration; a proposed approach to performing the human health risk assessment (HHRA) and baseline ecological risk assessment (BERA); preliminary remedial alternatives; and preliminary data requirements, including for Site characterization, risk assessments, and remedial alternative evaluation.

The information presented in the CSM Technical Memorandum has been used as the primary basis for this FIP, with more recent work at the Site and other Vermont copper mines (Ely and Elizabeth) used to refine the CSM.

3.4 Other Studies

Other studies of the Site and nearby areas which were not used for CSM development are listed below.

- *USGS, 1984*: collection of gold samples to determine their source. The distribution of gold-bearing samples suggests that the gold is from local bedrock sources, likely from massive sulfide deposits and/or metamorphosed sediments.
- *USGS, 1990a*: the leaves of several birch species were analyzed to assess the use of airborne spectroradiometric data. The leaves were found to contain anomalous concentrations of several metals including copper and zinc, which were correlated to anomalous spectral signatures for forest canopy surrounding the Eureka and Union Mines.
- *USGS, 1990b*: sediment samples were collected in the watersheds associated with the mines. Anomalous cobalt, copper, and zinc concentrations were noted in sediment associated with the Site.
- *Slack et al., 2001*: ore samples were combined with structural geologic evaluation of the Vermont mines, including the Site. The results suggested that the sulfides were formed in a rift setting.

4.0 PRELIMINARY CONCEPTUAL SITE MODEL

The current understanding of Site contaminant sources, release mechanisms, migration pathways, and conceptual model of groundwater flow at the Site are summarized in this section based on existing data.

4.1 Surface Water Hydrology

Based on studies by USGS, the primary source of impact to surface water is derived from the interaction of water from snow melt, rain, and groundwater percolating through the piles of waste rock and tailings, which subsequently transport low pH, metal-laden water and sediment downgradient into PHB and the tributary to Cookville Brook. PHB extends approximately 7 km from the Site to the confluence with the Waits River. Copper concentrations in PHB immediately upstream of the confluence range from 4.3 to 30 micrograms per liter ($\mu\text{g/L}$), with two of four samples exceeding a chronic toxicity standard (USGS, 2007b).

4.1.1 Eureka and Union Mine Watershed

The Eureka and Union mines are located in a broad but well-defined, moderately-sloping valley which forms a major portion of the headwaters to PHB. As a result, the contribution of flow to PHB from this mines is considerable and the downstream water is highly dependent on the composition and volume of the runoff from these areas. The headwaters of the PHB tributary are formed by multiple groundwater seeps observed between the former ore mill and lower Union Mine waste rock piles that coalesce into a perennial stream below the lowermost waste rock piles. They have an estimated range of flow between 0.01 and 2.5 cubic feet per second (cfs) prior to entering PHB (USGS, 2007b).

Considering the steep topography in the upper elevations of the Site, it is anticipated that precipitation will infiltrate downward, recharge groundwater in the overburden and

bedrock, and move laterally and downward toward the discharge areas defined by the tributary streams in the lower portions of these valleys.

USGS characterized the surface water hydrology at the Site starting at the tributary to PHB that drains the Site, beginning at the weir immediately above Richardson Road. USGS observed rapid fluctuations in the flow of the tributary to PHB during significant rain events. This suggests a generally low permeability and/or low storage capacity of the overburden and shallow bedrock, resulting in considerable overland flow and rapid discharge of shallow groundwater to the seeps and tributaries (USGS, 2007b). The ephemeral nature of the seeps at the Site also suggests that the baseflow observed year-round in the lower portions of these tributary valleys is derived largely from bedrock groundwater discharging upward through the overburden in these areas. The volume of mine pool discharge directly from Eureka and Union Mine openings to the surface appears to be minor, as no streams have been identified from these locations.

USGS sediment and surface water results from seeps and tributary streams indicate that the PHB waters are impacted by acidification and elevated metals concentrations. These metals are assumed to be derived from the mine rock and tailings piles, resulting in exceedances of regulatory criteria along the entire length of PHB (USGS, 2006; USGS, 2007a). Copper concentrations in surface water entering PHB from the Site range from 1.9 to 30.8 milligrams per liter mg/L (mg/L). The pH measured in the tributary to PHB ranged between 2.7 and 4.4 (USGS, 2007b). Copper was detected in the sediment in the tributary to PHB downgradient of the waste rock piles at a concentration of 8,070 milligrams per kilogram (mg/kg), comparable to that of the waste rock (USGS, 2006).

4.1.2 Smith Mine Watershed

The Smith Mine area is located along the western flank of a narrow south-facing valley drained by a 1.6 km long tributary to Cookville Brook. The headwater to this tributary is

located upgradient of the mine and does not appear to have any significant branches in the vicinity of the mine. The tributary passes within 500 ft of the mine waste rock piles, and USGS identified at least one significant seep along its bank downslope of the mine, although no surface drainage has been observed discharging directly from the Smith Mine pool. Stream flow in the Cookville Brook tributary was estimated between 0.19 and 0.63 cfs during two observations by USGS (USGS, 2007b). Copper concentrations in surface water downstream from the mine ranged from 3.6 to 11 micrograms per liter ($\mu\text{g/L}$) with a pH of 7.9. Only one of three samples collected exceeded a chronic toxicity standard. However, a seep water sample collected from the bank of the Cookville Brook tributary downgradient of the mine had a copper concentration of 5,030 $\mu\text{g/L}$ and a pH of 4.4. A copper concentration of 539 mg/kg was detected in a sediment sample from this tributary (USGS, 2006). As a result, the magnitude of the potential impact to this tributary and to Cookville Brook from the Smith Mine appears to be less significant than the observed impact of the Eureka and Union mines on PHB.

4.1.3 PHB Wetland Complex

The PHB Wetland Complex is located approximately 3.5 km downstream of the Eureka and Union mines and is a downgradient receptor to surface water impacts originating from these mines. Generally, the major element geochemistry of the wetland sediment samples was similar to that of the lower reach of PHB. In prior investigations, sulfur was observed to be greater in the wetland sediment samples than in PHB sediment samples, with concentrations ranging up to 11.2 weight percent sulfur in the former. Trace elements had higher maximum concentrations in the wetland sediment, and several exceeded their respective probable effects concentrations (PECs), especially copper and zinc.

In most sediment cores collected in the PHB wetland complex, metals typically had decreasing metals concentrations with depth. Also, sediment screening criteria exceedances were more frequent in the wetlands than surface water exceedances,

which was the opposite of observations within PHB itself. These observations suggest that acidic and oxygenated surface water containing dissolved metals discharges from the mines and flows down PHB. When this mine-impacted water enters the wetland, it flows through the wetland sediments, where it encounters increasingly more anaerobic and reducing conditions with depth in the sediment column (conditions that promoted by the organic substrate within the wetlands). Under these conditions, dissolved metals precipitate out of solution as metal sulfides. Therefore, under the current conditions, the wetland complex is acting as a geochemical sink for mine-related metals that are discharged through PHB. Trace elements may be remobilized to surface water in the lower reaches of the wetland as groundwater encounters the oxidized conditions of PHB (USGS , 2012).

4.2 Geology

The Site geologic features pertinent to the preliminary CSM are described in the following subsections.

4.2.1 Overburden Geology

Existing Site soil data are limited to shallow depth characterization of waste source areas which focused on the mineralogical and chemical characterization of the mine wastes. The natural subsurface soils at the Site are not well characterized. Site overburden is likely comprised of glacial till, typically a variably dense, poorly sorted, non-stratified deposit comprised of clay to cobble-sized material of variable thickness. Based on the relatively steep topography at the Site and the extent of bedrock exposure, glacial till at the Site is expected to be relatively thin (less than 10 feet). The thickest deposits are expected in the central part of the valley along the tributary to PHB. This area is also overlain in part by waste rock and tailings piles which are estimated up to 20 to 30 feet thick and likely represent the largest volume of overburden at the Site. The waste rock pile materials are derived from processing of

the ore and host rock by hand-cobbing and typically consist of a broad grain size range from silt to boulder-size material, while tailings tend to be finer, better sorted and more distinct mineralogically due to the more efficient separation used to generate them.

Based on the Site history, shallow soils are likely to be widely disturbed. PAL identified the lateral extent of waste rock piles during their survey of archaeological features; however, the potential impact of these waste areas on surrounding soils will require additional characterization.

4.2.2 Bedrock Geology

The bedrock at the Site is exposed at many locations in the upper elevations of Pike Hill. Bedrock is primarily composed of the Waits River Formation, a calcareous pelite/schist with minor amounts of mafic metavolcanic rock (amphibolite). These rocks were deformed during three stages of folding and amphibolite-grade metamorphism during the Acadian Orogeny. The orientation of foliation within the local bedrock is anticipated to be variable because of the complexity of this deformation. The ore zones are described as being stratiform and stratabound and occur in sheet-like lenses that follow the same orientation as the layering within the country rock. The ore zones consist of pyrrhotite and chalcopyrite, with minor sphalerite and pyrite, and strike approximately north-south with a dip of about 30 degrees east (Slack et al., 2001).

Additional data documenting the occurrence and orientation of Site bedrock fractures were not available; however, this data will be important in interpreting contaminant migration and groundwater flow in the bedrock. Remnant or unmined ore may continue to impact the existing mine pool and the surrounding bedrock.

4.3 Hydrogeology

Due to the moderately steep slopes at the Site, natural soil overlying bedrock is likely to be thin (i.e. less than 10 feet) and as such will have a limited capacity to store groundwater. Groundwater in the bedrock is largely stored in open fractures and flooded underground workings (described in more detail in Section 4.4). Where interconnected, fractures can form a considerable reservoir of groundwater. In addition, the underground workings form unique reservoirs of groundwater which may play an important role in the subsurface hydrology of the Site.

There are currently no monitoring wells at the Site and as a result, the groundwater conditions at the Site can only be interpreted from surface observations. Liquid precipitation that falls on the Site percolates vertically downward through the surface soils (i.e. waste rock, tailings, or native soil) and into the underlying overburden and/or shallow bedrock. In general, it is expected that the undisturbed, native tills would have lower hydraulic conductivities than the waste rock. In some areas where the native till is thin or exceptionally well drained (i.e. conductive), or where waste rock directly overlies bedrock, the overburden may be fully unsaturated. In these areas, the primary groundwater flow paths are within bedrock.

The upper elevations of Pike Hill (i.e. above the levels of the mine pools) are inferred to be an area of recharge, where downward vertical gradient allow precipitation to infiltrate down through thin overburden and into the fractured bedrock. In areas overlying the underground workings, groundwater may be intercepted and flow through the workings until it reaches the mine pool. In the case of the Eureka Mine pool, there is likely some flow at or close to the surface, maintaining the hydraulic head of groundwater in bedrock in the vicinity of the mine. If the mine pool is perched, such that the elevation of the mine pool is above that of the surrounding bedrock, then water from the mine pool will tend to recharge the surrounding bedrock. Based on the water

levels observed at adits to the three mines, flow from the uppermost part of the mine pool may be influencing shallow groundwater in these areas (USGS, 2006).

It's inferred that shallow groundwater mimics the Site topography and flows to the northeast and east, toward the lower elevations of the tributary and PHB. Deeper groundwater may be directed in a more easterly or southeasterly direction in response to regional scale discharge areas or local pumping stresses. Extreme fluctuations in stream flows over short duration in response to precipitation events were observed by USGS (USGS, 2007b) and attributed to: moderately steep terrain, low groundwater infiltration rates, and limited storage capacity in the thin overburden. Significant rain events and snow melt may also result in local mounding of groundwater in areas overlain by the waste piles due to their likely higher permeability and storage capacity. The lower portion of the PHB tributary valley has gentler slopes, and multiple seeps have been observed in and around waste rock piles. The seeps define an area of local discharge extending downslope to Richardson Road, likely fed by shallow overburden and bedrock discharge.

In the vicinity of the Smith Mine, shallow overburden and bedrock groundwater is anticipated to flow southeast toward the Cookville Brook tributary. Deeper bedrock groundwater may flow in a more southerly direction influenced by more regional scale discharge areas. The limited volume of waste rock and reportedly small scale of the underground workings there may limit the potential impact on groundwater. Bedrock outcrops identified in the Cookville Brook tributary streambed near the Smith Mine suggest that the quality of bedrock groundwater in this area will have a strong influence on surface water quality (White and Eric, 1944).

Based on limited Site information and the preliminary interpretation of groundwater conditions, waste rock piles may impact groundwater and overland flow in the upper elevations of Pike Hill, while the discharge of shallow groundwater in the lower portions of the valley may prevent the potential impact to deeper groundwater in those areas.

The potential impact from the mine pools depends on the bedrock fracture network. In addition, unmined massive sulfide ore remaining within Site bedrock in may also impact groundwater quality and complicate interpretation of the effects of mining on groundwater quality. Groundwater use in the vicinity of the Site limited, with some private drinking water wells in the immediate vicinity and downgradient of the Site. Information was not available on the quality of groundwater from nearby drinking water wells. Data documenting the orientations, frequency, and interconnectedness of fractures and joints within bedrock at the Site were not available; however, this data will be important in interpreting groundwater flow in the bedrock.

4.3 Contaminant Sources

Historical mining operations at the Site have resulted in deposition of waste rock and tailings, which are the source of acidity, metals, and sulfate impacts migrating off site. The Site consists of three separate mines and associated waste areas: Union Mine, Eureka Mine and Smith Mine. Figure 4-1 depicts the potential exposure areas.

The Union and Eureka Mines are located along the crest of Pike Hill, extending along the northeast flank of the hill within the PHB watershed. The Smith Mine is located on the southeastern flank of Pike Hill, within the Cookville Brook watershed. Each of these areas is overlain by a series of surface waste rock piles. Remnant historical archaeological features such as former mining-related building and equipment foundations are associated with the mine openings and waste rock piles. Variations in the ore processing resulted in differences in characteristics of wastes that are found on-site. The use of flotation separation techniques produced tailings piles, which are generally distinguished from ore and waste rock due to their finer (sand-sized) and more homogenous grain size. Hand processing of ore generally resulted in cobble to boulder sized materials mixed with finer waste rock. This material comprises the majority of waste rock piles at the Site. A magnetic separation process used for a short time near

the end of the mining history produced distinctly fine and concentrated mineral wastes. These wastes are identified in limited areas near the former Eureka mill location.

Previous work by USGS and VTDEC have characterized significant impacts to PHB and biological impairments related to ARD emanating from the Eureka and Union mining areas. Lesser impacts to a tributary of Cookville Brook have been documented related to Smith Mine activities. The mine pools of the flooded underground workings may also impact groundwater in the vicinity of the mines, although direct surface discharge from the mines appears to be limited.

USGS results from waste rock and tailings pile samples indicates that the majority of the waste rock piles are similar in character to waste rock at the Elizabeth and Ely mines, which were derived from ore deposits of very similar composition. Composite sample results from waste piles at the Site indicate that the waste rock piles appear to have similar composition and acid-generating potential, with the exception of the flotation and magnetic separation tailings. Flotation tailings tend to contain a higher concentration of pyrrhotite as a result of the removal of the chalcopyrite ore and are somewhat more susceptible to weathering and combustion, as evidenced by reported smoldering of portions of these piles in the early 1980s (PAL, 2011). Magnetic separation tailings tend to contain high concentrations of quartz and feldspar and low sulfide concentrations as a result of the removal of the metal-bearing minerals.

The mine waste pile locations and locations of the pertinent mine features and remnant historical features have been mapped in detail by PAL as shown on Figure 2-2 (PAL, 2011). Cross-sections depicting the major source areas (underground workings and waste areas) are provided in the accompanying figures. The cross-sections locations are shown in Figure 4-2 and the cross-sections themselves are provide as Figures 4-3 through 4-7. The following subsections describe the individual source areas.

4.3.1 Union Mine

Potential contaminant sources at the Union Mine include waste rock and the underground workings, as described below.

Waste Rock Piles: Waste rock associated with the Union Mine consists of approximately 11 separate or overlapping piles located in the north-central and lowermost portion of the valley. The largest waste pile area consists of three overlapping piles filling a portion of the center of the valley. Tailings were not identified in the Union Mine waste piles. Cross-section A-A' (Figure 4-3) depicts the Union mine waste area. Due to the apparent compositional similarity and their spatial distribution along a line extending down the center of the valley, these piles are grouped together and proposed as a single human health risk exposure area for risk characterization. The piles are located generally downslope from the Union Mine openings and underground workings. Because they occupy the lower elevations and are centrally located in the valley, they have a greater potential to interact with surface runoff from Pike Hill and discharging groundwater and mine drainage than upslope waste piles. Two seeps drain from this area, and the stream draining the valley runs along the southern margin of these piles. No significant distinguishing features have been noted between individual piles other than their size and location. The total waste volume at the Union Mine is estimated to be 15,430 cubic yards (Table 4-1). Two composite soil samples were analyzed by USGS from the larger piles in this area with copper concentrations between 3,670 and 8,410 mg/kg (USGS, 2006).

Underground Workings: The underground workings underlie an area approximately 250 feet wide by 750 feet long, and slope 25 to 30 degrees downward along the dip of the ore body to the northeast of the upper adit (White and Eric, 1944). The mine has two shaft openings located at the most upslope point (Union Mine Shaft) and an adit located near the central portion of the workings (Union Mine Adit). Cross-section B-B' (Figure 4-4) depicts the Union mine underground workings. The underground workings appear

to be nearly completely flooded up to the level of the Union Mine Adit. Water samples from the mine pool at the Union Mine Adit and uppermost portal to the Union Mine Shaft analyzed by USGS had copper concentrations of 1,800 µg/L and 4,950 µg/L, respectively (USGS, 2006). The extent to which water from the mine pool is migrating via overland flow appears to be minimal but is not well-documented.

4.3.2 Eureka Mine

Potential contaminant sources at the Eureka Mine include waste rock piles, the flotation/magnetic separation mill area, and the underground workings, as described below.

Waste Rock Piles: Waste rock piles associated with the Eureka Mine extend from the peak of Pike Hill to the north and northeast along the northeast facing slope of Pike Hill. Cross-section C-C' and D-D' (Figures 4-5a and 4-5b) depict the Eureka Mine waste area. The waste rock piles are grouped into three subareas based on location relative to the mine workings: piles northeast of the Eureka Mine Lower Adit; between the Eureka Mine Lower Adit and Eureka Mine Upper Adit; and the peak of Pike Hill. Due to their apparent compositional similarity and the spatial distribution along the length of the underground workings, these three waste rock pile subareas are proposed as a single human health risk exposure area for risk characterization. The total waste volume at the Eureka Mine is estimated to be 19,275 cubic yards (Table 4-1). The subareas are described separately below.

Northeast of the Eureka Mine Lower Adit are approximately twelve closely clustered and overlapping waste rock piles covering the steep slope extending between the Eureka Mine Lower Adit and the former mill foundation. These piles appear to fill the area at the head of the main tributary that drains the valley. USGS analyzed one composite soil sample from one of the larger piles in this group with a copper concentration of 8,060 mg/kg (USGS, 2006).

Between the Eureka Mine Lower Adit and Eureka Mine Upper Adit are six relatively small, tightly clustered waste rock piles. The piles are more than 200 feet from the lower piles (described above) and no seeps have been identified in this area. The piles appear to lie above the elevation of the mine pool and are not likely to interact with mine drainage. However, drainage from this area may contribute to the mine pool. One composite sample and one grab sample analyzed by USGS had a copper concentration of 3,240 mg/kg (USGS, 2006).

There are approximately 14 waste rock piles of varying sizes distributed along the crest of Pike Hill along the west and northwest side of the open cut, near the Eureka Mine Upper Shaft and immediately west of the Eureka Mine Upper Adit. Half of the piles are overlapping or tightly clustered near the Eureka Mine Upper Adit. Others are distributed uphill of the open cut, and a cluster of three small piles are located west and downslope of an old access road along the western flank of Pike Hill. Unlike the areas described above, several of the individual piles in this area appear to be located outside the PHB watershed, in areas likely draining to the west and south (Cookville Brook). No seeps were identified in this area. These waste piles appear to lie above the mine pool and are not likely to interact with mine drainage. However, drainage from this area may contribute to the mine pool. USGS analyzed two composite soil samples and one ore rock grab sample from the waste rock piles in this area, and copper concentrations ranged from 3,000 to 4,410 mg/kg (USGS, 2006).

Flotation/Magnetic Separation Area: This subarea includes the former ore processing mill and four overlapping piles of flotation tailings, partially burnt tailings, and magnetic separation tailings located immediately north of the former mill foundation. A separate and smaller pile of magnetic separation tailings is located immediately northwest of the former mill foundation. The main tributary that drains the valley is located on the northwest margin of these piles. A seep emanates from the downslope/northeast margin of these piles. USGS analyzed one composite soil sample from burnt tailings;

one composite sample from magnetic separation tailings; and grab samples from each of the red, gray, and yellow-colored waste layers within the piles for characterization. Copper concentrations from the tailings ranged from 7,200 to 9,200 mg/kg (USGS, 2006).

Underground Workings: The underground workings are located south of the Union Mine and extend northward from the Eureka Mine Upper Shaft near the peak of Pike Hill to the Eureka Mine Lower Adit. E-E' and F-F' (Figure 4-6a and Figure 4-6b) are cross-sections of the Eureka Mine underground workings. The ore body and related workings appear to follow the same northeasterly dipping trend as the Union Mine. The Eureka Mine underground workings underlie an area of approximately 200 feet wide by 600 feet long, sloping downward to the northeast from the open cut at the peak of Pike Hill along the 25- to 30-degree dip of the ore body. Four mine openings have been identified from south to north: Eureka Mine Upper Shaft, Eureka Mine Upper Adit, Eureka Mine Lower Shaft, and Eureka Mine Lower Adit. A water sample from the mine pool at the Eureka Mine Lower Adit analyzed by USGS had a copper concentration of 1,980 µg/L (USGS , 2006). The mine appears to be flooded up to this level, which suggests the uppermost portion of the mine is not flooded. The extent to which mine pool water is actively seeping from the mine via overland flow appears to be minimal but is not well-documented.

4.3.3 Smith Mine

The Smith Mine is located approximately 0.4 miles south of the peak of Pike Hill, within the Cookville Brook watershed. The mine area consists of the collapsed Smith Mine Adit with three nearby waste rock piles, the largest of which is immediately downslope of the adit portal. A series of exploratory trenches were dug in the hillside between the Smith and Eureka Mine areas, but no mining of ore occurred in this area, and no waste rock containing ore is known to exist in this area (PAL, 2011). Cross-section G-G' (Figure 4-7) depicts the Smith Mine.

Waste Rock Piles: The total waste volume at the Smith Mine is estimated to be 1,700 cubic yards (Table 4-1). No seeps are identified in the immediate vicinity of the Smith Mine waste piles; however, the unnamed tributary to Cookville Brook is located approximately 500 feet downslope of the waste rock piles and a bedrock seep has been identified along the bank of the brook (USGS, 2006). Three composite soil samples (one from each waste rock pile), four grab samples, and a soil composite sample from a downslope area were analyzed by USGS. Copper concentrations ranged from 1,380 to 1,800 mg/kg (USGS, 2006).

Underground Workings: The Smith Mine underground workings are within an area approximately 75 feet wide by 100 feet long extending westward from the shaft location, which is the only existing opening to the mine (PAL, 2011). The collapsed adit to the mine extends eastward from the shaft location. The underground workings appear to be completely flooded to a level just below the main shaft. No surface seepage of the mine pool has been observed. The mine pool is shallow enough to allow sampling from the surface, below the main adit opening. USGS analyzed a water sample from the mine pool at the main shaft location with a copper concentration of 992 µg/L (USGS, 2006).

4.3.4 PHB Wetland Complex

The PHB Wetland Complex includes four separate wetlands designated from downstream to upstream as Wetland 1 through Wetland 4. Elevated copper and iron concentrations are present in shallow wetland soil within the four wetlands (USGS , 2012). To date, the studies have been focused on Wetland 3 which appears to contain the highest concentrations of metals, (1 to 2% copper in localized areas, comparable to waste rock concentrations). Elevated copper and iron concentrations were detected throughout the sampled areas of Wetlands 3 and 4, with copper concentrations typically in the range of 100 to 3,000 mg/kg. The preliminary CSM proposed by the

USGS suggests the wetland is behaving as a natural geochemical sink where surface water containing dissolved metals from the Site enters the wetland, infiltrates the wetland soil, and precipitates metal sulfides in soil under the reducing conditions in the upper reaches of the wetland. Metals appear to be remobilized to surface water in the lower reach of the wetland, as the groundwater encounters oxidizing conditions as it enters the stream. Therefore, this area may represent a potential source area and will require additional characterization to assess the potential impact to the wetland soils.

4.4 Contaminant Migration

There are four primary mechanisms that can release and transport contaminants at the Site: surface water runoff, leaching into groundwater, seeps, and erosion.

Surface water runoff occurs during precipitation events or snow melts when contaminants in the soil and waste piles are released and transported to other areas on-site and off-site via Site drainage features. Precipitation, snow melt, surface water, and groundwater which comes into contact with iron sulfide ore minerals, dominantly pyrrhotite, in the waste rock/tailings and bedrock results in weathering (oxidation) and leaching of the ore and host rock through a series of chemical reactions that define the primary mechanism by which acid drainage is generated at the Site (USGS, 2001; Hammarstrom et al., 2001). The resultant low pH of drainage from these sources carries significant concentrations of elements and base metals that along with high acidity and high sulfate concentrations impact the surface waters downstream from the Site.

Groundwater from within the underground workings also contribute to the release of contaminants through the discharge of acid mine drainage via surface flow from mine openings and through fractures in the bedrock.

Overland flow of surface water results in the erosion of waste materials, transporting of potentially acid- and metal-generating materials into the stream sediment downgradient of the Site. Due to the barren to poorly-vegetated nature of the surface waste materials, wind transport of fines also has the potential to spread these materials beyond the footprint of the piles. As a result, surface soil, subsurface soil, sediment, surface water and groundwater at and downgradient/downstream of the Site are potentially impacted by Site sources. Trophic transfer of contamination in the aquatic and terrestrial food chains as a result of surface water and sediment contamination is also a potentially important migration pathway.

5.0 HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT

The purpose of this section is to present a proposed approach to performing the Site HHRA and BERA. The Risk Assessments shall determine whether Site contaminants pose a current or potential risk to human health and the environment in the absence of any further remedial action. Nobis will address contaminant identification, exposure assessment, toxicity assessment, and risk characterization. The Risk Assessments will be used to determine whether remediation is necessary at the Site, provide justification for performing remedial action, and determine what exposure pathways need to be addressed by remedial action.

5.1 Human Health Risk Assessment Approach

The proposed approach for the HHRA is based on what is currently known about the existing contamination on the Site, the likely potential receptors and exposure pathways based on the current and future uses of the Site, and to a lesser degree, the HHRA's performed for the Elizabeth Mine Site and the Ely Mine Site.

5.1.1 Preliminary HHRA Exposure Pathway Analysis

The HHRA will focus on those human populations likely to be exposed to each of the potentially contaminated Site media currently and/or in the future. This approach ensures that the range of risks over various population subgroups are characterized for potential activities and land/water uses.

5.1.1.1 Exposure Media and Routes of Exposure

The potentially contaminated media include soil, surface water, mine pool surface water (open water at mine openings, accessible to wading trespassers or recreational visitors), sediment, groundwater, underground workings groundwater (to be considered as a potential future drinking water source, assuming the chemistry differs

from that found in the general overburden or bedrock groundwater), and fish tissue. The list below presents these media along with the likely routes of exposure:

- Soil – contaminants in the soil may be incidentally ingested and absorbed through the skin by exposed humans. In addition, contaminants adsorbed onto particulate released from the soil into the air would be available for inhalation.
- Surface Water – contaminants in the surface water may be incidentally ingested and absorbed through the skin by exposed humans.
- Mine Pool Surface Water – contaminants in the surficial expressions mine pool water may be incidentally ingested and absorbed through the skin by exposed humans. Any contact with mine pool water is expected to be of short duration.
- Sediment – contaminants in the sediment may be incidentally ingested and absorbed through the skin by exposed humans.
- Groundwater – contaminants in the groundwater may be ingested and absorbed through the skin by exposed humans while showering and bathing.
- Underground Workings Groundwater – contaminants in the groundwater may be ingested and absorbed through the skin by exposed humans while showering and bathing.
- Fish – contaminants in edible fish tissue may be consumed by anglers and their families.

There are several pathways of exposure that could possibly exist in the areas surrounding the Site, either currently or in the future, which are proposed to be eliminated from consideration in the HHRA. These include the consumption of game obtained while hunting (deer, waterfowl, etc.) in the area and the consumption of meat and possibly milk from cattle that might graze in areas contaminated with metals from

the Site. The reasons for eliminating these pathways from evaluation in the HHRA include:

- Minimal potential for the metals of concern (e.g. copper and iron) to bioaccumulate in the edible tissues of these animals. These pathways are typically of concern from potential exposure to lipophilic organic compounds like polychlorinated biphenyls (PCBs) and dioxin/furans. The likely contaminants at the Site are not lipophilic and are likely to be regulated by a number of mechanisms, such as metabolism and elimination that preclude the accumulation of significant concentrations in edible tissue or milk.
- Cattle (beef or dairy) would need a large area to graze and are typically fed a diet that consists of a significant portion of grain that would be expected to be grown outside of the area of concern. Potential grazing activities in areas with contaminated soils would likely be minimal.
- Deer generally range across hundreds of acres and would be exposed to a wide range of habitats, most of which would likely be completely uncontaminated by the Site. In addition, the most critical exposure to deer at this Site would be incidentally ingested soil (and possibly sediment to a lesser degree) and given the nature of the typical diet - browse (leaves and shoots of woody plants), forbs (broad-leafed weeds and flowering plants), and mast (fruits and nuts) - a deer would be unlikely to consume a significant amount of incidentally ingested soil. Also, given the number of sources of surface water available, it is unlikely that this would be a significant exposure route.
- Ducks typically feed on invertebrates and aquatic vegetation, and have a limited rate of sediment consumption. As noted above, the metals of concern, while potentially high in the sediment, are not likely to bioaccumulate to a significant degree in the edible tissue of ducks or other waterfowl.

In addition, given the nature of metals in general and the potential exposure pathways at this Site, other pathways such as ingestion, inhalation, incidental soil/sediment ingestion, and dermal absorption are likely to result in significantly higher exposures to both child and adult receptors than any of the above pathways. These exposures will be discussed qualitatively in the HHRA unless the Site investigation process provides evidence that one or more of these pathways could become critical in the evaluation of human health risks.

5.1.1.2 Potentially Exposed Populations

The HHRA will focus on those human populations likely to be exposed to the potentially contaminated Site media currently and/or in the future. There are a number of activities that may lead to contact with Site media including: riding all-terrain vehicles (ATVs), hunting, birding, horseback riding, spelunking, hiking, and adolescent gatherings. Of these activities, riding ATVs appears to be a common activity as indicated by the trails and tracks in and around the Site. In addition, there is a trailer located close to the Site which indicates potential current residential use. It will be assumed that the Site will be used for residential purposes in the future. Based on the CSM (see Section 4 and Figure 5-1) and the current and potential future land and water uses, five potentially exposed populations are proposed to be evaluated in the HHRA. These five potentially exposed populations include:

- Current/future recreational visitors (adolescent and adult) – the soil exposure to the recreational visitors will be based on riding ATVs since this is a common recreational activity at the Site that could result in an intensive level of soil contact. The ATV riding exposure will be based on conservative assumptions that will cover the potential exposure associated with other, less-intensive soil contact activities. It will be assumed that the recreational visitors contact the on-site piles and the surface soil surrounding the Site. Therefore, the incidental soil ingestion, the dermal contact and absorption, and the inhalation pathways

are proposed to be evaluated for these receptors. In addition to contacting the Site soil, the recreational visitors will also be assumed to contact the mine pool surface water while exploring the mines shafts, adits, and any accessible underground complexes. The duration and magnitude of contact with the mine pool surface water is expected to be low.

- Current/future swimmers/waders (adolescent and adult) – the swimmers/waders will be assumed to contact the surface water and sediment while engaging in recreational activities in downstream waterbodies (PHB and Cookville Brook). The incidental ingestion and the dermal contact and absorption pathways are proposed to be evaluated for these receptors.
- Current/future fish consumers – these receptors represent anglers who catch and consume fish from the impacted downstream waterbodies (PHB and Cookville Brook). It will be assumed that the anglers share their catch with other household members (i.e. young children). For the purposes of this document, recreational level fish consumption will be assumed. However, the degree of potential fish consumption (subsistence or recreational) will be determined for each potentially impacted downstream waterbody as the HHRA process evolves. Subsistence level consumption will be evaluated if it is determined that a waterbody has both the ability to produce enough fish of edible size to support subsistence level ingestion and the presence of any local subpopulations that are likely to ingest a large amount of fish. Based on preliminary information, subsistence level consumption of fish obtained from PHB and Cookville Brook is not likely. It may be possible that Waits River can support subsistence level consumption. However, this has not been confirmed.
- Current/future residents (young child and adult) – it is possible that the nearby residents use the Site on a regular basis. This type of exposure is assumed to continue into the future. Therefore, residential exposure will be evaluated for the current and future uses of the Site. The current residents will be assumed to

contact the surface soil and the future residents will be assumed to contact the surface and subsurface soil as a result of soil mixing during future excavation and construction activities. The incidental soil ingestion, the dermal contact and absorption, and the inhalation pathways are proposed to be evaluated for residential receptors. Local area residents currently use groundwater as their source of potable water. This is expected to continue in the future. It is not known if the local residents' groundwater is impacted by the Site. Exposure to groundwater assuming the local residents ingest the groundwater underlying the Site through the ingestion and showering/bathing exposure routes will be evaluated for both current and future use scenarios. The current resident scenario will utilize data from existing residential wells. Two future use scenarios will be evaluated. The first using on-site groundwater data and the second using underground workings groundwater data.

- Future construction workers – the Site may undergo some type of construction activities at some point in the future, which may result in contact with surface and subsurface soil (top 10 feet assumed). Therefore, the incidental soil ingestion, the dermal contact and absorption, and the inhalation pathways are proposed to be evaluated for these future receptors. The duration of intensive contact with the Site soil during construction activities such as excavation is expected to be short.

The generation of dust containing contaminants as a result of wind erosion, riding ATVs, and construction activities and the subsequent inhalation by exposed populations is an important route of potential exposure for the Pike Hill Copper Mine Site. EPA's *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (SSG) (EPA, 2002) will be used to estimate emissions. Dust emissions as a result of wind erosion will be modeled to evaluate residential inhalation exposure. Emissions as a result of heavy truck traffic on unpaved roads will be used to estimate inhalation

exposure to recreational visitors while riding ATVs and to workers during construction activities.

5.1.2 HHRA Exposure Areas

The first step in developing the HHRA approach is to determine the manner in which the Site will be divided into exposure areas (EAs). The Pike Hill Copper Mines Site will be evaluated based on the existing array of waste and tailings piles, the current and potential future land and water uses, the on-site drainage features, and downstream waterbodies. The EAs will be determined to enable the HHRA to focus on specific areas and exposure media and estimate risks for those areas and media alone. Table 5-1 presents the proposed EAs, by media, for the Site. The proposed EAs are discussed in the following subsections.

5.1.2.1 Soil Exposure Areas

A total of six soil EAs are proposed (see list below). Figure 4-1 provides the extent of the proposed soil EAs.

- Combined Transitional zones at Union Mine and Eureka Mine,
- Combined Union Mine and Eureka Mine waste rock piles,
- Combined Magnetic separation tailing piles associated with the Union Mine and Eureka Mine,
- Combined Flotation separation tailing piles associated with the Union Mine and Eureka Mine,
- Transitional zones at Smith Mine, and
- Smith Mine waste rock piles.

As presented on Figure 4-1, the proposed soil EAs are large. The EAs were delineated based on the assumption that the contaminant levels and Site use are relatively similar within each area. If the analytical results from the collected samples or observations recorded indicate any specific areas of elevated contamination or obvious use, the extent of the soil EAs may be modified. Exposure doses and risks (cancer and noncancer) will be calculated for each soil EA in the HHRA.

5.1.2.2 Surface Water, Sediment, and Fish Exposure Areas

The surface water and sediment EAs were identified based on the waterbody and considered the length of the EA and waterbody characteristics such as morphology and flow regimes. A single surface water and sediment EA is proposed for the Union and Eureka Mines:

- PHB downstream to the wetlands complex (note: this EA does not include the on-site tributary to PHB).

Two surface water and sediment EAs are proposed for Smith Mine including:

- Unnamed tributary to Cookville Brook - the unnamed tributary is not on site. However, it potentially receives runoff from the Smith Mine area. The unnamed tributary is approximately 1.6 kilometers (km) in length.
- Cookville Brook downstream to the South Branch of the Waits River.

The need to evaluate the potential exposure and the specific sampling locations to be utilized within the off-site surface water and sediment exposure areas in Waits River will be determined after the on-site sampling results have been evaluated. It is possible that the Site contamination is not adversely affecting surface water and sediment in the Waits River. It is assumed that the streams and seeps (perennial and ephemeral)

located on Site will not be frequently contacted by any individual and that the amount of water does not provide a significant exposure potential. Therefore, on-site exposure to surface water (with the exception of mine pool surface water) and sediment will not be evaluated.

PHB and Cookville Brook will be investigated to determine if the waterbody supports edible fish communities. Impacted areas generally do not have fish that people would consume (e.g. trout) and, therefore, dace will be used as a proxy for trout. The available dace data will be compared to the Region 3 fish risk-based concentrations (RBCs). If the dace concentrations are less than the RBCs, it is likely that the concentrations in edible fish will not be of concern. If the datasets allow, trout concentrations will be predicted using the dace data and the available trout data.

Mine pool surface water will be evaluated separately for the Union Mine Area and the Eureka Mine Area.

It is assumed that the streams and seeps (perennial and ephemeral) located on Site will not be frequently contacted by any individual and that the amount of water does not provide a significant exposure potential. Therefore, on-site exposure to surface water (with the exception of mine pool surface water) and sediment will not be evaluated.

5.1.2.3 Groundwater

A number of monitoring wells are proposed to be drilled and sampled. These wells will be associated with the Union Mine Area, the Eureka Mine Area, and the Smith Mine Area. The data associated with these wells will be evaluated in the HHRA. Groundwater from the Union Mine and Eureka Mine Areas will be evaluated together as a single exposure area. Upon review of the data, these areas may be split. Groundwater from the Smith Mine Area will be evaluated as a separate exposure area. Overburden in

combination with shallow fractured bedrock will be evaluated separately from deep bedrock groundwater.

Underground Workings Groundwater will be evaluated separately for the Union Mine Area, the Eureka Mine Area, and the Smith Mine Area.

5.1.2.4 Additional Operable Units

It is assumed that the following areas will be considered by EPA at a later date, as one or more separate Operable Units (OUs), if necessary. Accordingly, this FIP does not include proposed risk assessment or field investigations activities in these study areas.

- the PHB wetlands;
- the PHB wetlands downstream to the Waits River; and
- Waits River.

5.1.3 HHRA Exposure Parameters

The exposure parameters that will be used to calculate the exposure doses (chronic daily intakes or CDIs) for each receptor population through the applicable exposure routes are presented in Tables 5-2 through 5-6. Two types of exposure doses will be calculated depending on whether the contaminant is considered to be carcinogenic. In the first model, the doses will be averaged over the assumed exposure duration and will be used to evaluate the potential for noncancer health effects (i.e. the average daily dose [ADD]). The second model, in which the doses will be averaged over a 70-year lifetime, will be used to evaluate potential carcinogenic risk (i.e. the lifetime average daily dose [LADD]). The exposure doses will be expressed as either administered (oral, inhalation) or absorbed (dermal) doses, in milligrams of contaminant per kilogram body weight per day (mg/kg-day).

To ensure that the risk estimates will be conservative and protective of human health, the intakes will be based on a combination of average and upper-end, typically the upper 90th or 95th percentile, exposure parameters. Many of the proposed exposure parameters are default values recommended by EPA in various current risk assessment guidance documents. In some cases, professional judgment was used to develop the proposed parameters. In other cases, additional work still needs to be performed to determine the exposure parameters.

5.1.3.1 Current/Future Recreational Visitors

Table 5-2 presents the proposed exposure factors for the recreational visitors. The adolescent will be assumed to be exposed from 10 to 18 years of age. Thus, the exposure duration (ED) for the adolescent will be 8 years. For the adult, an ED of 20 years will be used based on the assumption that the adult visitor is a nearby resident. The adolescent body weight (BW) will be 57 kg. This value is the average body weight for males and females ages 10 to 18 (see Table 8-14 NHANES 1999-2002 of EPA, 2011). The adult body weight will be 80 kg (EPA, 2014).

- The recreational visitors will be assumed to be exposed to Site soil for 8 months of the year (April through November) for 3 days/week (assumes 4.33 weeks per month). This equates to an exposure frequency (EF) of approximately 104 days/year. The visitors are not expected to contact the soil during January, February, March, and December.
- The incidental soil ingestion rate (IRS) will be assumed to be 100 mg/day. This value represents the adult IRS conventionally used for residential exposure (EPA, 2014). The fraction ingested (FI) will be 1.0 indicating that 100% of the amount of ingested soil will be come from the Site.

- The exposed skin surface area (SA) for soil exposure will be assumed to consist of the head, hands, forearms, lower legs, and feet. Using the data provided in the EPA's *Exposure Factors Handbook*, (Tables 7-1 and 7-8 in EPA, 2011), the SA for the adolescent will be 5,230 cm². Using the data provided in the EPA's *Exposure Factors Handbook*, Tables 7-2 and 7-12 (EPA, 2011), the SA for the adult will be 6,032 cm². The soil-to-skin adherence factor (AF) for the adolescent will be based on the geometric mean value for the heavy equipment operators' activity (0.2 mg/ cm²) (EPA, 2004). The AF from this activity was selected for the recreational visitors because it is assumed to represent an upper-end activity for individuals riding ATVs. The dermal absorption factors (ABS) will be obtained from RAGS Part E (EPA, 2004).
- Inhalation of dusts generated while riding ATVs will be evaluated by assuming that the recreational visitors will be at the Site for a total of two hours. As previously mentioned, the particulate emission factor (PEF) will be calculated based on heavy truck traffic on unpaved roads according to the SSG (EPA, 2002).
- The recreational visitors will be assumed to be exposed to the mine pool surface water once a month for 5 months of the year (May through September) when the weather is conducive to water contact activities. Each exposure event will be assumed to last for one hour. The incidental surface water ingestion rate will be assumed to be 0.05 L/hour (EPA, 1989). Dermal contact with the mine pool surface water will be assumed to occur to the head, hands, and forearms. Contact with the legs and feet is likely to be avoided. Thus, the SAs for the adolescent and adult will be 2,318 cm² and 3,470 cm², respectively. These values were calculated using the EPA's *Exposure Factors Handbook*, Tables 7-1 and 7-8 for the adolescent and Tables 7-2 and 7-12 for the adult (EPA, 2011). The dermal permeability coefficient (Kp) will be obtained from RAGS Part E.

5.1.3.2

Current/Future Swimmers/waders

Table 5-3 presents the proposed exposure factors for the swimmer/waders. The ED and BW values described in Section 5.1.3.1 for the recreational visitors will also be used for the swimmers/waders. However, the swimmers/waders will be assumed to be exposed to sediment and surface water for 5 months of the year (May through September) when the weather is warmer and conducive to water contact activities for 1 day/week (assumes 4.33 weeks per month). This equates to an EF of approximately 22 days/year. The swimmers/waders are not expected to contact the surface water and sediment during January through April and October through December.

- The IRS will be assumed to be 100 mg/day. The FI will be 1.0.
- The SA for sediment exposure will be assumed to consist of the head, hands, forearms, lower legs, and feet. Therefore, the SAs for the adolescent and adult will be 5,230 cm² and 6,032 cm², respectively. The AF will be based on the geometric mean value for the reed gatherers (0.32 mg/cm²) (EPA, 2004). The AF from this activity was selected for the swimmers/waders because it is assumed to represent an upper-end activity for individuals wading and contacting sediment.
- Each surface water exposure event will be assumed to last for 2 hours. The incidental surface water ingestion rate will be assumed to be 0.05 L/hour. While swimming, it will be assumed that the individual is fully immersed. Thus, the SAs for the adolescent and adult will be 15,900 cm² and 20,900 cm², respectively.

5.1.3.3

Current/Future Fishermen

Fish data from the prior aquatic investigations performed by USGS (see Section 3.2) in Pike Hill Brook and Cookville Brook (and tributaries) will be evaluated for the HHRA. The historical and RI data sets for Pike Hill Brook and Cookville Brook will be evaluated to

determine if the waterbody supports edible fish communities. Impacted areas generally do not have fish that people would consume (e.g. trout) and, therefore, dace will be used as a proxy for trout. The available dace data from the prior USGS investigations will be compared to the Region 3 fish risk-based concentrations (RBCs). If the dace concentrations are less than the RBCs, it is likely that the concentrations in edible fish will not be of concern. If the datasets allow, trout concentrations will be predicted using the dace data and the available trout data.

Table 5-4 presents the proposed exposure factors for the fishermen. The total ED will be assumed to be 26 years (6 years for young child and 20 years for adult). The residential EF of 350 days/year will be used. The child BW will be 15 kg (EPA, 2014). The fish ingestion rate (IRF) has not yet been determined. Further evaluation is needed to determine the degree of consumption (i.e. subsistence level versus recreational level). After this is determined, a regional-specific IRF will be proposed.

5.1.3.4 Current/Future Resident

Table 5-5 presents the proposed exposure factors for the residents. The total ED will be assumed to be 26 years (6 years for young child and 20 years for adult). The EFs will be 350 days/year for both soil contact and groundwater contact.

- The IRS values will be assumed to be 100 mg/day and 200 mg/day for the adult and child, respectively (EPA, 2014). The FI soil will be assumed to be 1.
- The SA will be assumed to be 2,690 cm² for the child (head, hands, forearms, lower legs and feet) and 6,032 cm² for the adult (head, hands, forearms and lower legs) (EPA, 2014). The AF for the child will be the geometric mean value for the daycare child (0.2 mg/ cm²). The adult AF will be the geometric mean value for the resident gardener (0.07 mg/ cm²). The SA and AF values proposed to be used are default values for residential exposure as recommended by EPA.

- Inhalation of dusts generated as a result of wind erosion will be determined by conventional techniques presented in the EPA's *Supplemental Guidance for Inhalation Risk Assessment* (EPA, 2009).
- The groundwater ingestion rate (IRW) values will be assumed to be 2.5 L/day and 0.78 L/day for the adult and child, respectively (EPA, 2014).
- The SA for exposure while bathing/showering will be 6,378 cm² and 20,900 cm² for the child and adult, respectively. The child bathing time will be 0.54 hour/event and the adult showering time will be 0.71 hour/event (EPA, 2014).

5.1.3.5 Future Construction Worker

Table 5-6 presents the proposed exposure factors for the construction worker. The adult construction worker will be assumed to be exposed for 60 days/year (i.e. 5 days/week for 12 weeks). The IRS will be assumed to be 330 mg/day (EPA, 2017a). The FI is assumed to be 1. The SA will be assumed to consist of the 50th percentile values for head, hands and forearms of the male and female (i.e. 3,470 cm²). The AF will be 0.2 mg/ cm², which represents the geometric mean value for heavy equipment operators. As previously mentioned, the PEF will be calculated based on heavy truck traffic on unpaved roads according to the SSG (EPA, 2002).

5.1.4 HHRA Metals Toxicity and Bioavailability Considerations

Currently, established toxicity factors are not available in the Integrated Risk Information System (IRIS) data base for key metals including cobalt, copper, and iron (EPA, 2017b). However, toxicity data are currently available for copper, cobalt, and iron from alternate sources, including Provisional Peer Reviewed Toxicity Values (PPRTVs) (EPA, 2006 and 2008) and the 1997 *Health Effects Assessment Summary Tables* (HEAST) (EPA, 1997). Toxicity factors for copper, cobalt, and iron from these sources were used for the Ely Copper Mine HHRA and for the reevaluation of HHRA risks at the Elizabeth

Mine conducted for the 2014 and 2019 Five Year Reviews. This same approach will be used in the HHRA risk calculations for Pike Hill.

Chromium speciation data will be used to determine the toxicity values most appropriate for use in evaluating total chromium data.

Based on EPA's Framework for Metals Risk Assessment (EPA, 2007a) and EPA's Guidance for Evaluating the Oral Bioavailability of Metals in Soils for Use in Human Health Risk Assessment (EPA, 2007b), there may be a need to adjust the potential exposure to account for the differences in absorption between the form of the metal assumed in the derivation of the toxicity factor (slope factor or reference dose) and the form of the metal assumed to be present at the Site. In 2014, the EPA performed in vitro bioaccessibility assays (IVBA) to evaluate the likely bioavailability of arsenic, cobalt, copper, iron, and lead at Elizabeth Mine. The arsenic, cobalt, copper, and iron IVBA values developed were reported as methods development research values only. The results of the site-specific IVBA evaluation of lead in soils were used to modify the bioavailability inputs to the IEUBK lead model. It is not expected at the present time that more detailed studies on bioavailability, such as an animal feeding study with juvenile swine, would be considered for this Site. The IVBA values developed for Elizabeth Mine will be used to modify the exposure inputs for metals in soils at Pike Hill Mines.

5.1.5 Considerations of Background Sampling Results

Soil sampling of background areas will be conducted to provide comparisons and context to site soil metals concentrations. In general, it is expected that site soil concentrations will exceed background for predominant risk drivers. However, background data may be useful for evaluating detected analytes that lack toxicity values. Site-specific background data might also be useful for establishing clean-up goals.

5.1.6 Data Considerations

X-ray fluorescence (XRF) data will be used to aid in selecting samples to send to the laboratory for analysis off-site and for characterizing the Site. Typically, XRF data are not used for the HHRA. However, the XRF data will be summarized and a statistical evaluation will be performed of the paired XRF data and the laboratory data to determine the comparability and consistency of the data. If the results of the paired sample comparisons indicate that there is relatively good comparability between the laboratory and XRF results (as was found at the Ely Mine Site), XRF data will be included in the HHRA.

5.2 BERA Approach

Based on the SOW and additional guidance from EPA, there will be two BERAs developed for the Site: a terrestrial BERA and the aquatic BERA that focuses on impacts to Pike Hill and Cookville Brooks, their tributaries and the Waits River (EPA, 2007c). The aquatic BERA, produced by EPA in the summer of 2008, is focused on the water channels and the aquatic ecosystems present therein. Included in this assessment are semi-aquatic receptors that forage on prey items living in the water channels, exclusive of the PHB wetland complex. However, it should be noted that some data collected for the aquatic BERA (e.g. surface water) also will be used to assess risk to selected receptors evaluated in the terrestrial BERA. Where possible, receptors and exposure pathways for each of the risk assessments will remain distinct; the only exposure overlap currently identified is the surface water ingestion pathway which will be common to many of the receptors proposed. Consideration of the use of adjustment factors to evaluate metal bioavailability, as discussed in Section 5.1.4, will also be explored when assessing exposures to ecological receptors.

The remainder of this discussion focuses on exposure pathways, areas and receptors for the terrestrial portions of the BERA. It is anticipated that as more baseline information is collected for the wetlands complex (see Section 8.2), the ecological risk assessment will be adjusted to reflect a better understanding of contaminant fate and transport mechanisms within these areas.

5.2.1 Preliminary BERA Exposure Pathway Analysis

Potential ecological exposure pathways illustrate ways in which stressors (e.g. contaminants) are transferred from a contaminated medium to ecological receptors. The following is a list of exposure pathways by which terrestrial and wetlands receptors may be exposed to chemical contamination at the Site:

- vascular plants - direct contact with soil;
- vernal pool community (if present) - direct contact and ingestion of vernal pool water, sediments, and ingestion of vernal pool biota;
- soil invertebrate community - ingestion and direct contact with soil; and
- birds and mammals - ingestion of surface soil, surface water, and food (e.g. plants, soil invertebrates, and small mammals).

These potential exposure pathways are illustrated in the ecological Exposure Pathway Analysis (Figure 5-1). It should be noted that the CSM also includes an evaluation of vernal pools that will be done if present at the Site. Any vernal pools identified and assessed would be included in the terrestrial BERA. A more detailed discussion of the vernal pool evaluation process is provided in Section 8.2 (Data Needs for the BERA).

5.2.1.1 Exposure Media and Routes of Exposure

In addition to the direct or indirect ingestion of contaminated soil, the potential for food chain impacts of bioaccumulative chemicals (e.g. metals) in terrestrial systems is well recognized. Because of the significant bioaccumulation potential associated with copper and several other metals present at the Site, and the potential risk to terminal receptors in the food chain, representative upper trophic level receptors are evaluated as part of the BERA. Because carnivores and omnivores generally represent the terminal receptors in terrestrial systems, avian and mammalian species foraging upon resident biota may be at substantially higher risk than those receptors at a lower trophic level. The ingestion of surface waters presents at and downgradient from the Site is also a pathway of concern for most of the endemic, higher trophic level organisms.

5.2.1.2 Potentially Exposed Populations

Two populations were identified for potential exposures:

- Terrestrial: The terrestrial BERA cannot evaluate potential adverse effects to every plant, animal or community present and potentially exposed at the Site. Therefore, receptors that are ecologically significant, of high societal value, highly susceptible, and/or representative of broader groups are typically selected for inclusion in the BERA. Table 5-7 is a list of proposed terrestrial receptors and communities to be evaluated and their associated exposure area(s). Specific exposure pathways for each receptor are provided in Figure 5-1.
- Aquatic: As with the terrestrial BERA, the aquatic BERA cannot evaluate potential adverse effects to every plant, animal or community present and potentially exposed at the Site. A detailed risk evaluation for Pike Hill and Cookville Brooks was conducted in 2008. The proposed aquatic assessment as

part of this RI is limited to the collections and analysis of surface water and sediment samples throughout each brook and comparing those results to concentrations and findings from the 2008 aquatic assessment. The four wetland areas located along PHB prior to its discharge into the Waits River are not included as part of this assessment.

5.2.2 BERA Exposure Areas

The following contiguous areas are proposed as potential exposure areas for the terrestrial and wetlands BERAs; however, should additional information indicate the presence of hot spots or unique exposure conditions, these areas could be further subdivided to address risk at a more localized scale. It should be noted that existing waste and tailings piles (which have little or no vegetation and are known to contain contaminant levels and environmental conditions resulting in adverse ecological impacts) are not recommended for evaluation in the terrestrial BERA. It is assumed that the primary source areas will be addressed during subsequent remediation activities.

- Terrestrial habitat bordering the sources areas – due to their spatial separation, this exposure area will be divided into two units: one for the Eureka and Union Mines; and one for the Smith Mine. Biological sampling for the terrestrial BERA will focus on the vegetated transitions zones adjacent to and down-gradient from the waste piles.
- Surface waters (i.e. PHB and tributary, Cookville Brook and tributary, and the Waits River) – the terrestrial BERA will evaluate the surface water ingestion pathways for appropriate target receptors; depending on data availability and further understanding of Site transport conditions, water chemistry data from some of these water bodies may be combined.

- Other riparian floodplain areas – if further investigation indicates contaminant migration into floodplain areas (note: these potential exposure areas and associated pathways should be investigated during the RI process).

5.2.3 BERA Exposure Parameters

As was previously presented, receptors or target communities will be evaluated as part of the BERA (see Section 5.2.1.2). The evaluation of plant, soil, and sediment will be accomplished using a combination of Site observations, community assessments, and benchmark comparisons (see Section 8.2.2 BERA Data Needs) for a more detailed presentation of proposed evaluation approaches).

For individual receptor species (e.g. American robin, short-tailed shrew, mink etc.), two general modeling approaches exist for quantifying risk that differ dramatically in the level of effort involved and their abilities to distinguish variability and uncertainty (Thompson and Graham, 1996). The most commonly used approach is the “point estimate” or “deterministic” approach, which involves selecting a single (conservative) value for each of the model inputs (parameters) from which a point estimate of risk (i.e. Hazard Quotient [HQ]) is generated.

Choosing single values for inputs reduces the level of effort required for the exposure modeling process, but unavoidably limits the discussion of uncertainty and variability in the risk characterization.

Deterministic exposure modeling represents one of many ways to characterize exposure. As was previously mentioned, a number of receptor-specific exposure models will be incorporated in this BERA. In an attempt to limit the effort expended as part of the exposure modeling process and still identify potential ecological risks, a “tiered approach” that includes a conservative worst-case (i.e. Reasonable Maximum

Exposure [RME]) and more realistic average (i.e. Central Tendency Exposure [CTE]) approach will be used). Whenever possible, species-specific exposure parameters will be taken from guidance provided in EPA's Wildlife Exposures Factors Handbook Volume I and II (EPA 1993a and 1993b) and Guidance for Developing Ecological Soil Screening Levels (EPA 2005). Specific exposure parameters that will be used in the modeling process will be provided to EPA prior to the initiation of the modeling process.

Exposure models used in this BERA take the following general form:

$$TDI = FT \times \left(FIR \times \sum_{i=1}^n C_i \times P_i \right) + SIR \times C_{sed} + WIR \times C_w$$

Where:

TDI	=	Total daily intake (mg/kg BW-day)
FT	=	Foraging time in the exposure area (unitless)
FIR	=	Body weight normalized food intake rate (kg WW/kg BW-day)
C _i	=	Concentration in the ith prey item (mg/kg WW)
P _i	=	Proportion of the ith prey item in the diet (unitless)
SIR	=	Sediment ingestion rate (kg DW/kg BW-day)
C _{sed}	=	Concentration in sediment (mg/kg DW)
WIR	=	Water ingestion rate (L/kg BW-day)
C _w	=	Concentration in water (mg/L)

Because of the difficulties in measuring intake of free-ranging wildlife, data on FIRs are not available for many species. Using FIRs for captive animals potentially underestimates the intake rates because these animals do not expend as much energy as their wild counterparts do, since activities for captive animals do not include behaviors such as foraging and avoiding predators. Therefore, allometric equations using measurements of free metabolic rates (FMRs) are used to determine FIRs.

The FMR represents the daily energy requirement that must be consumed by an animal to maintain among other things, body temperature, organ function, digestion, and reproduction. To maintain these physiological functions as well as to perform daily behavioral activities such as foraging, avoiding predators, defending territories, and mating, the animal must replace the lost energy by metabolizing and assimilating the energy in its food (i.e. its metabolic fuel). The balance between an animal's energy loss and replenishment is reflected in the quality and quantity of food in the animal's diet. Assuming that the animal's habitat supports a variety of food items, selection of diet may reflect a preference toward more energy-rich foods (i.e. higher gross energy), although one must consider the energy expended in pursuit of prey.

Not all food that is consumed by an animal is converted to usable energy. Depending on the digestibility of the dietary item and the physiology of a particular animal, a substantial portion of the energy may be lost through clearance. Assimilation Efficiency is a measure of the percentage of food energy (i.e. item-specific gross energy) that is assimilated across the gut wall and is available for metabolism.

The equation used to determine FIRs is as follows:

$$\text{FIR (g ww/g BW-day)} = \frac{\text{FMR}}{\sum_{i=1}^n (\text{AE}_i \times \text{GE}_i \times P_i)}$$

Where:

FIR = Body weight normalized field ingestion rate (kg WW/kg BW-day equals g WW/g BW-day)

FMR = Field metabolic rate (kcal/g BW-day)

AE_i = Assimilation efficiency of the ith food item (unitless)

GE_i = Gross energy of the ith food item (kcal/g)

P_i = Proportion of diet comprised of the ith food item (unitless)

5.2.4 BERA Bioavailability Considerations

A central underlying premise in evaluating the impacts of metals to ecological receptors is that they must be accumulated above, or in rare cases of deficiencies, depleted below normally regulated levels by the receptor in order for an effect to be elicited. The bioaccessibility, bioavailability, and bioaccumulation properties of inorganic metals in soil, sediments and aquatic systems are complex (McGreer and others, 2004). Similar to organic compounds, abiotic (i.e. pH, cation exchange capacity [CEC], total organic carbon [TOC]) and biotic (i.e. uptake and metabolism) modifying factors determine the amount of inorganic metal that interacts at biological surfaces (i.e. gut lining, epithelial tissue, or root-tips) and that binds to and is absorbed across these membranes. To better characterize the risk presented by metals in the environment to ecological receptors, the processes that affects metal speciation and the effects of speciation on metals bioavailability must be addressed through data collection or, at a minimum, acknowledged in the uncertainty analysis when evaluating ecological risks at sites where metals are the primary contaminants of concern.

Once absorbed or assimilated into biota, metals are subject to numerous fate and transport processes including storage, metabolism, elimination and accumulation. Unlike organic contaminants, some metals are essential nutrients and when not present in sufficient concentration can limit growth, survival and reproduction; another critical factor that must be included in any ecological risk assessment that is focused on metal contamination. Other critical factors that need to be considered when evaluating metals-related ecological risk are: 1) metals naturally vary in concentration across geographic regions and endemic organisms have evolved under these conditions, therefore, making and understanding of local background concentrations is important; and 2) metals occur in mixtures and can interact with each other in numerous ways including synergistically and antagonistically.

The BERA approach presented in this document tries to address some of the key issues identified by EPA in its Framework for Metals Risk Assessment (EPA, 2007a), thereby reducing some of the uncertainties frequently encountered in ecological risk assessments at sites where metals are the primary contaminants of concern.

5.2.5 Risk Estimation

In this screening assessment, risks will be estimated by comparing single-point estimates of exposure (i.e., a concentration or dose) with effects levels (TRVs). HQs will be developed to determine potential effects to target receptors from exposure to chemicals of potential ecological concern (COPECs) in soil/sediment and prey items. The HQ approach used for this evaluation simplifies the comparison process and allows for a more standardized interpretation of the results. The HQ reflects the magnitude by which the sample concentration or dose exceeds or is less than the toxicity reference values (i.e., soil screening level, ecological benchmark, criterion or estimated dose). In general, if a NOAEL-based HQ is less than 1, adverse effects are unlikely. If a LOAEL-based HQ exceeds 1, the potential for the exposure to elicit an adverse effect is likely. If the NOAEL-based HQ is greater than 1, but the LOAEL-based HQ is less than 1, the potential for adverse effects are undetermined. Although the HQ method does not measure risk in terms of likelihood or probability of effects at the individual or population level, it does provide a benchmark for judging potential risk (EPA, 1994).

HQs will be calculated specific to measurement receptor and exposure scenario location (e.g., habitat) evaluated as follows:

$$HQ = EEL/TRV$$

Where:

HQ = Hazard quotient (unitless).

EEL = estimated exposure level (Communities: medium concentration in units of mg COPEC/kg medium; or for dietary exposure to wildlife target receptors: estimated dose in units of mg/kg BW-day).

TRV = toxicity reference value (benchmarks mg COPEC/kg medium; or for dietary exposure to wildlife target receptors: dose in mg/kg BW-day).

5.2.6 Ecological Significance

The use of numerous ecological screening level benchmarks evaluates potential effects across several levels of biological organization, i.e., cellular, organism, population and community. Of particular concern in ecological risk assessment is the effect of contaminants on higher levels of organization where impact at the population and community level can potentially modify the ecological structure and function of a watershed or ecosystem. Factors considered in evaluating the ecological significance of any estimated risk will include spatial scale, temporal scale, habitat uniqueness, species and community vulnerability, and others.

5.2.7 Comparability with Background Concentrations

To distinguish contamination resulting from historical site activities with naturally occurring background or anthropogenic levels, a background comparison will be conducted. Those COPECs having levels lower than or similar to background levels will be eliminated as contaminants of concern (COCs) for consideration in the FS.

5.2.8 Uncertainty Analysis

Uncertainty is inherent in each step of the BERA process. Assumptions (generally conservative) are made to support those elements of the risk assessment process where chemical and physio-chemical data are absent or limited, where toxicological endpoints are extrapolated from species other than those being specifically evaluated,

and a number of other factors that affect the confidence level of the risk assessment. These factors may include:

- data analysis techniques and data availability limitations;
- appropriateness of TRVs and exposure model parameters for receptors at the site;
- appropriateness of the selected receptor species as surrogates for the indigenous community species;
- uncertainty and relative degree of overestimation inherent in exposure estimation; and,
- applicability of HQ calculations, where the numerator and denominator each represent deterministic estimates of risk confounded through the use of conservative assumptions.

Major factors contributing to uncertainty in this risk assessment as well as their potential impact on the assessment results will be discussed qualitatively. To the extent possible, the uncertainty analysis conducted for the Screening Level Ecological Risk Assessment (SLERA) will follow the approach and format recommended by EPA at http://www.epa.gov/region8/r8risk/eco_uncertainty.html.

5.3 Summary and Conclusions

This subsection will present a summary in narrative and tabular form of the results of the BERA for the Pike Hill Site. In addition, conclusions relevant to the ecological significance of the potential risk of site contamination to ecological populations and natural communities in the Pike Hill study area will be presented.

6.0 PRELIMINARY RESPONSE ACTION OBJECTIVES

This Section outlines the currently identified Applicable or Relevant and Appropriate Requirements (ARARs) for the Site, preliminary Project Quality Objectives, and preliminary approach to evaluating background conditions at the Site.

6.1 Preliminary Identification of ARARS

This section summarizes the preliminary identification of ARARs for the Site FS. The ARARs include those identified in the FS for the Elizabeth Mine Site (URS, 2006b) and for the Ely Mine Site (Nobis, 2011 and 2015). These ARARs will be reviewed throughout the RI program and revised as the FS process is implemented for the Site.

Section 121 of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (known as SARA), provides the statutory basis for ARARs. Specifically, Section 121(d) states that response actions must at least attain (or justify a waiver of) all ARARs or other federal environmental laws, more stringent state environmental laws, and state facility-siting laws.

A requirement may be either applicable or relevant and appropriate to remedial activities at a site (but not both). Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstances at a site. These requirements would be legally applicable notwithstanding CERCLA.

If a requirement is not applicable, it may still be relevant and appropriate. The basic considerations are whether the requirement:

1. regulates or addresses problems or situations sufficiently similar to those encountered at the subject site (i.e. relevance); and
2. is appropriate to the circumstances of the release or threatened release, such that its use is well suited to the particular site.

A requirement might be relevant but not appropriate for a specific site; in this case, the requirement would not be an ARAR. Determining whether a requirement is relevant and appropriate is site-specific, is based on best professional judgment, and considers a number of factors including the characteristics of the remedial action, the hazardous substances present at the Site, and the physical circumstances of the Site and of the release. The EPA maintains in its guidance that portions of a requirement may be relevant and appropriate (EPA, 1992).

Compliance with all requirements found to be applicable or relevant and appropriate is required under CERCLA. Waivers of ARARs may be obtained under certain circumstances in the following six areas:

- • interim measure;
- • greater risk to health and the environment;
- • technical impracticability;
- • equivalent standard of performance;
- • inconsistent application of state requirements; and,
- • fund-balancing.

These waivers apply only to meeting ARARs with respect to remedial actions onsite; other CERCLA statutory requirements, such as the requirement that remedies be protective of human health and the environment, cannot be waived.

“To be considered” items are non-promulgated advisories, proposed rules, criteria, or guidance documents issued by federal or state governments that do not have the status of potential ARARs. However, these criteria and guidance are to be considered only when determining protective cleanup levels where no ARAR exists, or where ARARs are not sufficiently protective of human health and the environment. In these circumstances, “to be considered” values may be considered in establishing remedial objectives.

6.1.1 Chemical-Specific ARARs

Chemical-specific ARARs are based on health or risk-based concentration limits or discharge limitations in environmental media (i.e. water, air) for specific hazardous chemicals. These requirements may be used to set cleanup levels for the COCs (in this case, metals) in the designated media.

Sources for potential target cleanup levels include selected standards, criteria, and guidelines that are typically considered as ARARs for remedial actions conducted under CERCLA. The preliminary chemical-specific ARARs and other criteria or guidelines to be considered are discussed further below, and are summarized in Table 6-1. They are based on standards, guidelines, and criteria found in relevant literature, past discussions with appropriate Vermont regulatory agency personnel, and prior project experience.

6.1.2 Location-Specific ARARs

Location-specific ARARs are restrictions placed on the types of activities that may occur in particular locations. The preliminary location-specific ARARs for the Site are presented in Table 6-2. The location of a site may be an important characteristic in determining its impact on human health and the environment; thus, state standards often establish location-specific ARARs. These ARARs may restrict or preclude certain remedial actions or may apply only to certain portions of a site.

6.1.3 Action-Specific ARARs

Action-specific ARARs are technology- or activity-based requirements or limitations on actions taken to implement a proposed alternative. These requirements are triggered by the particular remedial activities that are selected to accomplish a remedy. Since there are usually several alternative actions for any remedial site, very different requirements come into play. These action-specific requirements do not in themselves determine the remedial alternative; rather, they indicate how a selected alternative can be achieved. Preliminary action-specific ARARs are listed in Table 6-3.

6.2 Other Regulations or Restrictions Impacting RI/FS Activities

Other regulations that may be applicable to the RI/FS activities at the Site would include:

- Occupational Safety and Health Administration (OSHA) regulations for worker health and safety;
- Low Risk Site Handbook for Erosion Prevention and Sediment Control, VTDEC, August 2006;

- Construction General Permit (CGP) 3-9020, VTDEC, August 2006 for permitting stormwater discharges from construction activities to prevent erosion and control sediment discharges; and
- American Society for Testing and Materials (ASTM) Guidance, as appropriate.

6.3 Preliminary Project Quality Objectives

The objectives of this project are to provide information to characterize the nature and extent of contamination at the Site, support evaluation of human health and ecological risks, and facilitate the evaluation of remedial options relating to historical mining activities at the Site. The data generated for this project will be used to: assess potential impacts to Site media attributable to mine-related activities; to assess whether Site conditions pose an unacceptable risk to human health and ecological receptors; and to support the selection and design of appropriate remedial actions to mitigate risks. Data generated from this project will vary in type, quality, and quantity dependent on the specific intended purpose and methods used. In general, data generated from field methods will tend to have the lowest quality and those generated by fixed, off-site laboratory analysis using established analytical methods will have the highest quality.

A sampling and analysis plan (SAP) consisting of a field sampling plan (FSP) and a quality assurance project plan (QAPP) will be prepared following the EPA QA/R5 requirements for QAPP development (EPA, 2001) to define quality assurance (QA) procedures that will be followed during the course of the project. Laboratory analytical data will be evaluated in terms of precision, accuracy, representativeness, completeness, comparability, and sensitivity to determine their usability for the intended purpose. Field data characterizing surficial soils and mine waste materials, groundwater, surface water, and sediment will be used to confirm the presence or absence of environmental impacts, define the nature and extent of identified impacts,

support the human health and ecological risk assessments, and to develop and evaluate remedial alternatives.

The SAP will specify Data Quality Objectives (DQOs) and other QA procedures (e.g. standard operating procedures) that will be developed and followed to ensure that RI/FS field measurements, sampling methods, and analytical data provide information that is representative of actual field conditions, is of sufficient quality to support decision making, and is technically and legally defensible.

6.4 Site Background Analyte Evaluation

A background analyte evaluation is required to provide a set of reference numbers for various media and chemical constituents that aid in the comparison of detected chemicals to chemicals attributed to former mining operations. The background data reflects conditions that are not influenced from releases at the Site, but result from natural or other non-mine related sources. These reference concentrations are specific to the areas in which the data are collected and are referred to as site-specific background or background in this report. The background data is not used to eliminate chemicals of potential concern (COPC), but rather is used to evaluate contribution to Site risks from non-mine related activities, and to distinguish those contributions from the risk contributed by the Site contaminants. Background is considered in risk management decisions under CERCLA and communication of risks in the decision making process.

Establishment of appropriate site-specific background concentrations requires a careful examination of the available data by statistical methods. Also required is the inclusion of practical considerations such as the quantity and quality of the data, and the resolution of issues such as the presence of unlikely chemical constituents in what are regarded as background sampling locations. The statistical methods that will be employed to characterize background data sets include: testing for the distribution of

data; selection of parametric or non-parametric methods; determination and resolution of apparent outlier values; use of descriptive statistics; and finally, the establishment of the proposed background data set concentration measures using a 95 percent upper confidence limit (UCL) on the mean or other rule (i.e. the maximum), when all other statistic requirements are not met.

The initial findings of the RI field investigations will be used to determine which analytes and media are required in a background concentration evaluation as well as to design a specific background evaluation study. However, based on our current understanding of the Site indicating that the COPCs are limited to inorganic compounds, a background evaluation of volatile organic compounds (VOCs), Pesticides/ PCBs, and selected semivolatile organic compounds (SVOCs) (primarily polycyclic aromatic hydrocarbons [PAHs]) is not anticipated to be required. Ultimately, the selection of specific analytes for background evaluation and statistical analysis will be based on a compound's potential risk to human health or the environment, as identified in the screening level risk assessment.

7.0 POTENTIAL REMEDIAL ALTERNATIVES

Section 7.0 presents an overview of the process and selection of potential remedial alternatives for the Site, categorized by identified source areas. In addition, potential treatability studies are presented based on review of the Site data and associated existing remedial technologies.

7.1 Development of General Response Actions

General Response Actions (GRA) are broad categories consisting of remedial technologies and process options that can be selected individually or in combination in order to meet the Remedial Action Objectives (RAOs) for the Site. GRAs are included in the FS process to give a range of responses for consideration for site remediation. GRAs would include: no action, limited action, containment, removal and disposal/discharge, in-situ treatment, ex-situ treatment and resource utilization.

7.2 Technology Evaluation

In this section, potentially applicable technology types and process options for each GRA identified above are presented and undergo an initial evaluation. The evaluation is provided in Tables 7-1 through 7-4, which are arranged by medium. For the purpose of this document, “technology types” refer to general categories of technologies, such as biological treatment, vertical barriers, and institutional controls, whereas “technology process options” refer to specific processes within each technology type, such as phytoremediation, slurry walls, and deed restrictions.

During the screening process, process options and entire technology types may be eliminated from farther consideration. As stated in Section 4.2.5 of Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (EPA, 1988), the evaluation of process options at this stage is based upon three screening criteria:

- Effectiveness;
- Implementability; and
- Cost

Viable process options are retained for incorporation into remedial alternatives. Although the various process options are discussed and evaluated individually, combinations of process options are frequently used to accomplish site remediation. Possible combinations will be discussed during the development of remedial alternatives for each source area identified.

7.3 Evaluation Criteria

For any areas of the Site that are identified as requiring remedial action through the RI and HHRA/BERA, the FS will consider and develop remedial alternatives in accordance with CERCLA and NCP requirements as well as additional guidance documents available from the EPA. Alternative development is preceded by a brief description of the physical characteristics of each of the impacted areas. These are assessed against criteria specified in the NCP and EPA guidance. These criteria include the three screening criteria discussed above and the nine detailed criteria presented in the following paragraphs.

The EPA uses nine criteria to evaluate alternatives and select a final cleanup plan (called a remedial action) that meet the statutory goals of protecting human health and the environment, maintaining protection over time, and minimizing contamination. These nine criteria make up the assessment process used for all Superfund sites. Of the nine CERCLA-defined FS evaluation criteria, two criteria are threshold criteria and must be met by each remedial alternative to be considered applicable and appropriate for the remedy. These include:

- overall protection of human health and the environment; and
- compliance with ARARs.

Five of the remaining criteria are referred to as balancing criteria by which the alternatives are compared and upon which the analysis is based. These include:

- long-term effectiveness and permanence;
- reduction of toxicity, mobility, or volume;
- short-term effectiveness;
- Implementability; and
- cost.

The remaining two modifying criteria, state acceptance and community acceptance will be considered thoroughly by EPA prior to selection of the ROD remedy.

7.4 Potential Remedial Alternatives

Potential remedial treatment options for presumed Site source areas are identified in Tables 7-1 through 7-4 based on available technologies and process options. These presumed sources and potential remedial alternatives are preliminary and may not constitute all sources that may be identified during the RI or alternatives that would be initially screened and or retained for detailed evaluation during the FS.

The potential remedial treatment options are arranged by GRAs as follows:

- No Action – required by CERCLA and NCP requirements. Developed as a baseline to compare against all other response actions.

- Limited Action – involves a form of legal and physical deterrent to the site in order to prevent exposure to site contaminants.
- Containment – a physical system (i.e. capping, etc.) to contain the site contaminants and prevent exposure.
- Removal and Disposal – active removal and disposal of site contaminants from source areas which usually includes off-site disposal at secure facilities.
- In-Situ Treatment – a chemical and/or biological treatment process to reduce or eliminate site contaminants.
- Ex-Situ Treatment – a physical removal of site contaminants and treatment via chemical and/or biological processes which either be on-site or off-site.

During the FS evaluation, remedial alternatives will be developed by source areas (i.e. mine wastes, wetland areas, surface water, sediments, groundwater, and underground workings) based on an evaluation of the above-noted GRAs through the initial screening process. Several potential remedial alternatives will be retained for detailed evaluation and preferred alternatives ultimately selected for each source area.

7.5 Vermont Copper Belt Mine Site Remedy Review

While the Site has some unique characteristics, previous studies conducted at the Site have indicated that the geochemical composition of the mine waste, mine drainage, surface waters, and sediments are similar to the Elizabeth Copper Mine and Ely Copper Mine Superfund Sites (see Section 2.3). The Elizabeth Mine FS (URS, 2006b) and Ely Mine FS for OU1 and OU2/OU3 (Nobis, 2011 and 2015) were reviewed to evaluate potential remedial alternative available for the Site.

7.5.1 Elizabeth Mine Site

Following completion of the RI/FS, the EPA selected and performed the following remedial actions for the five areas of the Elizabeth Mine Site:

- Non-Time Critical Removal Action (NTCRA) – consolidation and capping of mine wastes in an on-site waste repository; active and passive treatment of tailing pile leachate; surface water diversions, and adit closure to eliminate ARD impacts to surface water.
- Lord Brook Source Area – consolidation and capping of mine wastes; mine pool dewatering and active treatment; surface water diversion to eliminate ARD impacts to surface water.
- Upper and Lower Copperas Factories – capping of lead-containing surficial soil to prevent direct contact.
- Sediments – Monitored natural recovery of the sediments in impacted surface waters.
- World War II Era Infrastructure Area – Monitoring of the surface water runoff to ensure no negative impacts to water quality downstream.
- Site Wide Groundwater – Institutional controls (i.e. land-use restrictions) and long-term monitoring to prevent groundwater consumption.

These removal actions designed and performed for the Elizabeth Mine may be applicable to Pike Hill and will be evaluated during the FS process.

7.5.2 Ely Mine Site

EPA selected the following remedial actions for OU1 (EPA, 2011) and OU2/OU3 (EPA, 2016):

- excavation of surficial soil and sediment sources (i.e. waste rock and tailings sources, and impacted sediment from Ely Brook and tributaries) and consolidation in an on-site capped waste repository to contain and isolate the material from contact with water and oxygen;
- closure by plugging or filling of the Lower Underground Workings (i.e. the Deep Adit) to reduce or eliminate discharge of mine-impacted water to Site surface water;
- operation and maintenance passive chemical treatment of any residual adit discharge;
- institutional controls (i.e. land-use restrictions to prevent 1) residential development; and 2) groundwater consumption);
- operation and maintenance of the remedial features; and
- installation of monitoring wells and long term monitoring and inspections to evaluate cleanup performance.

The removal actions designed for the Ely Mine may be applicable to Pike Hill and will be evaluated during the FS process.

7.6 Potential Treatability Studies/Pilot Testing

As the RI/FS process is conducted and Site investigation data is collected for the decision-making process, additional data may be collected and evaluated to support alternatives that are developed during the detailed analysis stage of the FS. This

involves data collection and/or treatability studies. Treatability studies may be conducted in situations where there is a need to collect additional data on certain technologies in order to determine if that technology is applicable to the Site. These studies may be conducted at both a bench-scale and a pilot-scale.

The objectives of treatability studies are to achieve the following:

- Provide sufficient data to allow remedial alternatives to be fully developed and evaluated during the detailed analysis and to support the selected alternative remedial design; and
- Reduce cost and performance uncertainties for remedial alternatives to acceptable levels in order to select a remedy.

The decision to conduct treatability studies would consist of the following:

- Determine the data needs for the Site;
- Review existing Site data and available literature on technologies to determine if existing data are sufficient;
- Perform treatability tests to determine performance, operating parameters and relative costs of potential technologies; and
- Evaluate the data to ensure that PQOs are met.

The need for treatability studies will be determined during the initial FS technology screening process. Based on prior FS and RD work performed at the Elizabeth and Ely mines, pilot studies may be beneficial in the following areas:

- passive and active water treatment pilot studies to determine metals loading rates, alkalinity dosing rates, required reaction and settling times, and treatment substrate design.

- geotechnical and agricultural testing to evaluate the suitability of on-site native materials to be used for remedial construction;
- surface soil test treatments for general waste stabilization and erosion control; and
- test plantings to evaluate cover soil and seed mixtures for general waste stabilization, wetland mitigation and Site restoration.

8.0 DATA GAP SUMMARY

The following sections describe the current data gaps.

8.1 Waste Rock/Tailings

The locations and visual characteristics of the Site waste rock and tailings piles were mapped and described previously (PAL, 2011; USGS, 2006). However, most of these investigations were limited to surface and near-surface waste rock. Additional work is needed to define the vertical (subsurface) and lateral extent of the waste rock and tailings piles, the extent of potential impacts away from the piles, and the chemical and physical characteristics of these materials at depth. Saturated soils, in particular, may have different geochemistry and impacts on the environment, and sufficient samples should be collected to compare both saturated and unsaturated conditions. Much of the waste is present in piles with extents and volumes that may be readily estimated. However, given the age of the material, the waste may also include a significant volume beyond the piles that may have been eroded and transported, or overgrown and become forested.

8.2 Soil

Very little surface or subsurface soil (as opposed to waste material) has been characterized at the Site to date. Additional evaluation is required to determine potential Site-related impacts and to support risk assessments, particularly in transitional areas that border the barren waste rock/tailings sources. In addition, impacted non-waste material may serve as a source of contamination for other downstream or downgradient media (groundwater, surface water, and sediment).

Additional on-site floodplain soil sampling is needed for the terrestrial BERA. Additional off-site floodplain sampling locations may also be necessary. The need to conduct off-site floodplain sampling will be determined based on the initial results of on-site soil

and surface water/sediment sampling as well as field observations of downstream floodplain areas that will be performed during off-site sampling activities.

8.3 Sediment and Surface Water

Existing data from USGS sampling conducted as recently as 2007 (see Section 3.2) provide characterization of surface water and sediment conditions at that time. Based on the unchanged conditions of the Site sources areas and downstream surface water channels, no significant attenuation of the previously observed impacts is expected on-site or off-site. However, given that the last sediment and surface water samples were collected over 12 years ago, additional on-site sampling is required to confirm current conditions and evaluate the tributary impacts in more detail (i.e. using more locations and sample analyses applicable to the RI process). Also, a limited off-site sampling program is needed to update the current contaminant nature and extent and provide data necessary to evaluate aquatic risks for the BERA. Also, the installation of a long-term weather recording station and surface flow monitoring stations using flumes and/or weirs is required to refine water flow estimates; groundwater-surface water interactions; and surface transport mechanisms:

8.4 Groundwater

No monitoring wells have been installed to date; therefore, Site impacts on groundwater are unknown at this time. Given that the surface mine pools and surface water in the vicinity of the Site are impacted by ARD, both near-surface and bedrock groundwater require evaluation.

Groundwater fate and transport can be estimated based on field observations of shallow depth to bedrock, steep slopes, and the presence of large volume of waste rock and tailings. However, the installation and testing of monitoring wells and boreholes

will be required to determine groundwater flow paths and degree of potential impact on off-site receiving media such as bedrock and surface water.

8.4.1 Overburden

Overburden groundwater may be considered both a receiving media (from bedrock and soil contamination) and a source of contamination to downgradient media such as surface water. The geochemistry and contaminant load of overburden are unknown at this time. Upgradient and cross-gradient wells should also be installed to determine background conditions.

The saturated thickness, hydraulic conductivity, gradients and flow direction, and geochemistry of overburden are unknown at this time. The installation of an overburden well network is required to provide evaluation of groundwater flow and quality.

8.4.2 Bedrock

A large amount bedrock data has been collected by the former mine operators and BOM to support mine expansion. Geologic studies have also evaluated the ore structure in detail. However, none of these investigations have been focused on implications for bedrock and contaminant migration. Current data gaps include bedrock characteristics relating to groundwater flow (e.g. fracture characteristics, expected bedrock flow paths, plume transport rates, etc.). A bedrock structural study should be performed to evaluate the large and small-scale structural influences on groundwater flow, including borehole geophysical logging for all proposed bedrock boreholes and photo-lineament analysis.

Specific mine-related on-site and off-site bedrock groundwater impacts are unknown at this time. The residences in the vicinity of the Site use bedrock water supply wells

(see Figure 2-5); therefore, the potential impact from the underground workings and any near-surface contamination should be evaluated, both downgradient of the workings and at the downgradient edge of the Site.

The installation of an on-site bedrock well network is required to provide evaluation of groundwater flow and quality. Upgradient and cross-gradient background wells should also be installed and completed as wells, as applicable, to determine background conditions. Bedrock groundwater evaluation should also determine the bedrock fracture regimes to develop an understanding of flow and transport pathways.

8.5 Underground Workings

The underground workings where they are flooded have the potential to be a source of contamination to the surrounding bedrock groundwater, and potentially to other downgradient/downstream receptors. Mine pool samples from the accessible portals exceeded water quality standards for metals and sulfate (USGS, 2006), and investigations at other copper mine sites in the area (EPA, 2006b; EPA, 2016) suggest that the mine pools are likely to be contaminated at depth as well.

To date, the Site mine pools have not been sampled away from the air-water interface. Samples collected at depth may have significantly different chemistry because of the low-oxygen environment. Borings and/or wells are required to access and evaluate the deeper portions of the mine pools.

Given that the underground workings are features within the bedrock, the current data gaps include those described above for bedrock in general.

Other data gaps for the underground workings include:

- the overall extent of the workings and mine pools laterally and with depth;

- the geometry and condition the workings, particularly workings that currently drain to surface water;
- the relationship between the underground workings drainage to surface water and groundwater, particularly as it relates to the flux rates of water, contaminants, and acidity.
- the potential impact of well pumping (such as for a residential water supply well) close to the mine pools;
- It is unclear whether the portals are the primary drainage feature for the workings, or whether a significant portion of the water entering the workings drains via subsurface fractures and seeps. An accurate water balance for the workings is necessary to determine potential remedial alternatives both for the workings themselves and for off-site surface water drainage.

8.6 Vernal Pools

The prior aquatic investigations performed by USGS (see Section 3.2) did not include a formal evaluation of vernal pools. In accordance with VTDEC guidelines (VTDEC 2003), a vernal pool assessment should be performed to identify, map, and characterize the conditions of all vernal pools (i.e. isolated depressional wetlands with no permanent inlet or outlet).

8.7 Biota

The prior aquatic investigations performed by USGS (see Section 3.2) in Pike Hill Brook and Cookville Brook (and tributaries) provides adequate fish data for the HHRA. No additional biota sampling is needed to support the HHRA or aquatic BERA. However, soil invertebrate and small mammal sampling is necessary to evaluate risks for the terrestrial BERA.

8.8 Failure Mode Effect Analysis

The Failure Mode and Effect Analysis (FMEA) is required to provide an evaluation of the potential risks posed by field investigations, remedial alternatives, and unrelated triggering events such as earthquakes and extreme weather. The structure, volume, and amount of water impounded in the workings is currently unknown; this volume of water presents a potential risk to individuals working at the Site, facilities such as access roads and Richardson Road, and ecological receptors if it were released by failure of impounding structures or by blockage of existing release points, causing additional structural stress. The impact of heavy equipment operation (e.g. drilling equipment, earthmoving equipment, etc.) during investigations and future remediation is unknown at this time. The data available for the Pike Hill mines are limited compared to the data available for the Ely and Elizabeth mines. The baseline investigation phase FMEA is included as Appendix A.

8.9 Engineering Requirements

The material properties of the waste rock and tailings may vary based on the ore processing method used. These properties, including grain size, hydraulic conductivity, structure, and drainage characteristics, will be required to determine stabilization requirements and suitability for use in construction for potential remedies. Native soil may be used in proposed remedies (such as cover) or may be consolidated elsewhere, and may also require geotechnical characterization.

9.0 PRELIMINARY DATA REQUIREMENTS

Section 9.0 presents requirements for additional data collection activities.

9.1 Project Quality Objectives

The data collection activities described in this FIP will be used to address existing data gaps that are relevant for the completion of the RI, development and updating of the FMEA, and to refine potential alternatives for the FS, given a presumptive remedy that will involve at least some degree of earthwork for waste materials.

Data generated from this project will vary in type, quality, and quantity dependent on the specific intended purpose and methods used. In general, data generated from field methods (e.g. XRF field screening) will tend to have the lowest quality and those generated by fixed, off-site laboratory analysis using established analytical methods will have the highest quality.

A QAPP will be prepared consisting of a FSP and a SAP following the EPA QA/R5 requirements for QAPP development (EPA, 2001) to define QA procedures that will be followed during the course of the project. Laboratory analytical data will be evaluated in terms of precision, accuracy, representativeness, completeness, comparability, and sensitivity to determine their usability for the intended purpose. Field data characterizing surficial soils and mine waste materials, groundwater, surface water, and sediment will be used to confirm the presence or absence of environmental impacts and to define the nature and extent of identified impacts.

The QAPP will specify DQOs and other QA procedures (e.g. standard operating procedures) that will be developed and followed to ensure that pre-design investigation field measurements, sampling methods, and analytical data provide information that is

representative of actual field conditions, is of sufficient quality to support decision making, and is technically and legally defensible.

9.2 Baseline Surveys

Baseline surveys will provide initial data to support the initial mine pool volume estimates and other risk factors to be included in the activity-specific FMEA that will be updated prior to implementing the more intensive subsurface field investigations (i.e. drilling into the workings). These initial surveys will also be used to accurately locate existing Site features and determine optimal locations for monitoring wells, surface water monitoring points, and full characterization samples (in conjunction with initial screening samples).

9.2.1 Ground-Based Feature Surveys

Ground-based surveys will be conducted at the Site to supplement existing information and provide sufficient details to prepare volume calculations to support the RI/FS. Ground based survey will be conducted in critical areas where finer detail is required, primarily the areas of the underground workings and significant open cuts. The proposed extent surveys are shown in Figure 9-1.

Prior to conducting the field survey, available Light Detection and Ranging (LiDAR) data will be reviewed to identify areas where supplemental/more detailed field survey data will be required.

A field reconnaissance and detailed topographic and existing conditions ground survey will be completed by a Land Surveyor registered in the State of Vermont with an accuracy to 0.01 feet of the following features:

- Previous BOM and mine owner borings

- Shafts, adits, and significant open cuts
- Surface Water Features: The location of streams bordering on or running through the surveyed property, including:
 - Detailed cross sections of potentially impacted streams at key locations where there are changes in brook geometry and at tributary confluences as determined by the hydrologic engineer during field reconnaissance. The field survey data for the cross sections will include the main channel, floodplain, overbanks, and water elevation. The main channel will include measurements at the top and toe of the bed as well as the lowest point in the channel.
 - Detailed topography of PHB, Cookville Brook, and their associated tributaries. Survey data will include the depth, elevation of the water, and V-notch weir crest and invert elevation. Field survey data for culverts within the watershed will include the size, type, length, and invert elevations.
- Subsurface Investigation Locations: the locations and elevations of all newly installed monitoring wells and piezometers. Any soil borings, test pits, geotechnical probes, surface soil and sediment transects will be surveyed by field staff using a Trimble global positioning system (GPS).
- Buildings, roads fences, stonewalls, signs, landscape features, topographic relief and other important natural and man-made features;
- Visible evidence of physical access (such as curb cuts and driveways) to any abutting streets or other public ways.
- Utilities: the location of any utilities along the Site frontage with Richardson Road, specifically overhead utilities and utility poles, and any storm water pipes or structures.

- Office reduction of field data, and plotting of field located features, based on field observations and record information and calculation of boundary and topography at a two-foot contour interval.

As part of the field reconnaissance/survey, permanent survey points will be installed to tie in future surveys as needed.

9.2.2 Laser Surveys

High-definition laser scanning LiDAR will be used for waste piles, steep/unstable slopes, areas of extensive open cuts/high variability in terrain (such as the eastern portion of the Union Mine) and at mine entrances. The laser survey area is shown in Figure 9-1. The mines will not be entered to ensure staff safety; instead, the surveys will be set outside the entrances to capture as much data as possible safely.

9.2.3 Underground Workings

Surface geophysics will be used to confirm the mapped extent of the underground workings and locate offshoots/other features that may not be mapped. Given the open portals and the relatively shallow nature of the upper portion of the workings, methods such as seismic, gravimetric, and electromagnetic (EM) surveys are expected to be viable.

The initial surface geophysics survey depicted in Figure 9-1 will be targeted to the areas of sensitivity (shallow workings and open cuts) to help target drilling locations, evaluate the condition of the near-surface underground workings, and provide more accurate mine pool volume estimates for the FMEA.

Follow-on surface geophysics will target areas of lower potential risk, such as the Smith Mine, the deeper workings, and the area between the Union Mine and Eureka Mine (if

the initial surveys indicate a potential connection between these features). This round of work will be performed if the workings are successfully identified and traced during the initial survey, and if additional work (vibration survey, revised mine volume estimates) indicate that additional surveys are warranted.

9.2.4 Bedrock Surveys

Nobis will conduct an initial non-intrusive bedrock investigation to evaluate potential fracture zones. Previous investigations performed by White and Eric (USGS, 1944) mapped the ore body and structural geology. The proposed RI bedrock evaluation will include additional evaluations to characterize the fractured bedrock and associated groundwater transport mechanisms, including:

- An air-photo photolineament evaluation will be conducted to evaluate potential large-scale fracture zones. These large-scale features would then be the target in part of field mapping activities. The photolineament evaluation will be performed using available aerial imagery, including 2016 LiDAR data.
- Geologic field mapping will be conducted to identify bedrock outcrops and their lithology, mineralogy, structure, weathering, and fracture characteristics (strike, dip, length, frequency, aperture, mineralization, wet versus dry, etc.).

9.2.5 Sensitive Receptor Surveys

The mine shafts and adits at the Site may house federally threatened and/or endangered bats. Biological surveys will be required prior to intrusive work and use of heavy equipment in and around the underground workings to ensure that these sensitive receptors are not adversely affected by the fieldwork.

9.2.6 Seep/Surface Water Survey

During high water conditions (e.g. spring melt out), existing seeps, pooled water, and streams will be identified, marked, and surveyed for inclusion in later sampling and water level flow/measurement events.

9.3 Nature and Extent of Contamination

Additional sampling is required to determine the nature and extent of contamination and support risk assessments for the RI. In addition, geotechnical parameters will be collected at the same time to support FS planning, enhance efficiency and minimize later remobilizations. Sample rationales, locations, and analytes are included in Table 9-1. Sample collection and management details will be included in the Site-specific QAPP.

9.3.1 Soil and Wastes

9.3.1.1 Surface Soil and Wastes

An initial XRF soil screening program will be used to delineate shallow waste areas and impacts. The approximate screening field investigation locations are shown in Figure 9-2. A summary of the sampling methodology, rationale, and analytical parameters is provided in Table 9-1.

Each XRF transect will start at the edge of the target waste area and will consist of test pits or hand-augered soil borings (HASBs) if mechanized access is not possible. The test pit or HASBs will be installed every 20 feet until waste (based on color and texture observations) is no longer encountered. Test pits will be installed to refusal or a maximum of 20 feet below ground surface (bgs); while the HASB locations are assumed to be surface soil samples (maximum of 2 feet bgs). XRF samples will be collected vertically every two feet, with a separate sample split taken and preserved for potential

paste pH and laboratory confirmation based on XRF results. The soils will be logged for soil classification, waste thickness, and other indicators of potential contamination. If XRF copper concentrations are detected above 500 mg/kg at the last location in a proposed transect, the transect will be extended to include an additional location 20 feet beyond the previous location.

Confirmation samples will be sent for laboratory analysis of metals and paste pH. Three samples will be sent from each transect, including: the sample with the highest concentrations; a sample with a copper concentration of less than 500 mg/kg below apparent waste (if waste appears to continue to bedrock/refusal, the deepest sample will be collected instead); and a surface sample of less than 500 mg/kg copper from the end of the transect.

Potential soil background study areas and proposed groundwater background well (MW-07 B, C, and D) locations are shown in Figure 9-2. The suitability of the proposed soil and groundwater background areas is suggested by the lack of historical mining activities in these areas of the Site as well as their upgradient setting to known areas of soil impact. The exact background soil sampling locations will be selected following an initial review of the XRF soil transect program results.

Prior to the performance of any subsurface explorations , qualified individuals will be consulted regarding the proposed locations of the explorations with respect to known historic resources and sensitive populations such as bats. The screening and waste extent delineation locations may be adjusted if the if the waste rock/topographic survey substantially revises the extent of the waste material piles or identifies new waste rock material.

9.3.1.2

Subsurface Soil and Waste

Soil borings are required to confirm depth to bedrock, install monitoring wells, and collect chemical characterization and geotechnical samples. Figure 9-2 depicts the soil sample locations. The soil borings will be installed using either hollow-stem augers (HSA) (if monitoring well installation is not planned at a given location) or drive and wash with casing for monitoring well locations. Soil samples will be collected for standard penetration test (SPT) values and laboratory analysis throughout the soil column, and upon refusal, bedrock will be confirmed prior to borehole abandonment or well installation. The following samples will be sent for laboratory analysis, if encountered:

- surface (depth needed for HHRA),
- unsaturated waste below the surface sample,
- saturated waste,
- native material immediately below the waste, and
- native material above bedrock

For planning purposes, five analytical samples are expected per boring. Soil sampling locations, analyses, and rationales are presented in Table 9-1.

9.3.2

Groundwater

The installation and monitoring of an on-site groundwater monitoring well network is necessary to characterize the nature and extent of Site-related contamination, evaluate fate and transport mechanisms, and quantify Site-related risks. This proposed network is shown in Figure 9-2. The drilling program will begin after the topographic survey, initial surface geophysics survey, and screening/waste delineation

are completed. The locations shown in Figure 9-2 may be adjusted based on the outcome of these initial surveys and waste delineations.

Borings will not be installed directly above any underground workings, with the exception of the bedrock boreholes intended to intercept the mine pools, to avoid potential damage to the workings. The bedrock boreholes to intercept the mine pools (MW-20 and MW-21) will be installed after the other bedrock drilling and vibration monitoring have been completed.

A comprehensive round of groundwater samples will be collected at least two weeks after the overburden and bedrock wells are installed. A synoptic groundwater measurement round will be conducted for all on-site monitoring wells before the start of each groundwater sampling round. One additional groundwater sampling rounds will be conducted targeting a different seasonal condition than the first event. If organic contaminants are not detected in the overburden during the first round, or are detected below screening criteria, they will not be analyzed for in these additional sampling rounds. However, if any organic results in shallow overburden do exceed screening criteria, those wells and any associated/nearby bedrock wells will be sampled for that analyte group.

The proposed groundwater background well cluster (MW-07 B, C, and D) is shown in Figure 9-2. The suitability of the proposed soil and groundwater background areas is suggested by the lack of historical mining activities in these areas of the Site as well as their upgradient setting to known areas of soil impact.

The proposed overburden and bedrock wells are described below.

9.3.2.1

Overburden

The proposed overburden monitoring well network (Figure 9-2) is designed to evaluate the contaminant contribution of each mine subarea, and the potential for contaminants to migrate downgradient/downstream. Borings for overburden monitoring wells will be completed using drive and wash cased boring methods as described in Section 9.4.1. Drilling will continue until bedrock is encountered. If shallow refusal (e.g. less than 10 feet) is encountered, up to two additional attempts may be made and a monitoring well installed if feasible in the deepest boring. Monitoring wells will be constructed of two-inch diameter, schedule 40 PVC with well screens sized appropriately for the material encountered. Monitoring wells will be screened within the bottom ten feet of native material above bedrock. Well screens may be shortened in the event of shallow refusal or if insufficient native material is available. However, if the soil column contains less than two feet of native material, the monitoring well may be screened in the waste material only (if enough saturated material is available).

Overburden groundwater samples will be measured in the field for select inorganic parameters (pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity) and collected with peristaltic pumps, using low-flow sampling methods. The samples will be submitted for analysis of select organic and inorganic parameters (see Table 9-1).

9.3.2.2

Bedrock

The bedrock well network (see Figure 9-2) is designed to evaluate: the potential for on-site groundwater plumes; impacts to groundwater related to the underground workings; background groundwater conditions; and potential off-site groundwater impacts (i.e. residential drinking water supplies).

Shallow and deep bedrock monitoring wells will be installed as companions to the overburden wells in order to characterize the bedrock aquifer(s). The data will be used

in conjunction with the overburden data to evaluate the potential interaction between surface water, groundwater, and the mine pools. In each bedrock well cluster, 15 feet of bedrock core will be collected for bedrock confirmation and rock quality designation (RQD) (to be limited to one bedrock core per well cluster). Bedrock groundwater wells will be completed as six-inch open boreholes.

Borehole geophysical logging will also be performed in each bedrock borehole (to be limited to one bedrock well per well cluster) to characterize the bedrock and select intervals for packer testing. The logging program will include the following suite of geophysical borehole logs/tests:

- fluid temperature and fluid resistivity (FT/FR);
- three-arm caliper (CAL);
- optical televiewer (OTV);
- acoustic televiewer, including acoustic caliper;
- 8", 16", 32", 64" Normal Resistivity (NR), Single-point resistance (SPR), Spontaneous Potential (SP); and
- intrawell heat-pulse flow meter (HPFM) under ambient and pumping conditions.

FT/FR data will be used to help identify hydraulically active fractures. Caliper data will be used to measure the diameter of the borehole and to locate packer intervals. Acoustic Televiewer and OTV data will be collected to determine the location and attitude of fractures exposed in each bedrock borehole. Electrical logs will be used to help identify the presence of hydraulically active fractures and possible changes in lithology. Intrawell HPFM logging will be used to determine the location of water bearing fractures under ambient conditions. Geophysical logging results will be used to make recommendations for bedrock packer sampling zones.

Following the geophysical logging, bedrock packer sampling will be performed targeting identified hydrogeologically significant fractures (i.e. fractures that are shown to be hydraulically active or show distinct geochemical or geophysical changes). Immediately following the packer sampling, the well will be allowed to re-equilibrate to its approximate baseline water elevation at which time one open borehole bedrock samples will be collected from each borehole. A second round of open borehole bedrock samples will be collected during the second round of Site-wide groundwater sampling (i.e. only one round of packer sampling is proposed). The bedrock groundwater packer and open borehole groundwater samples will be measured in the field for select inorganic parameters (pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity) and submitted for laboratory analysis of select inorganic parameters (see Table 9-1). Also, the boreholes will be tested for specific capacity during the packer sampling.

9.3.2.3 Mine Pool

Deep bedrock monitoring wells will be installed to intercept the flooded mine pool below the air-water interface at the Eureka and Union mines. Final locations are subject to change and will be determined based on the results of surface surveys. The target depths for the deep bedrock monitoring wells are 20 feet below the expected bottom of the workings in each location (see Table 9-1). Six-inch bedrock boreholes will be installed using fluid or air rotary methods. In locations where it is necessary to reduce vibrational energy to an absolute minimum, fluid rotary should be used. Each borehole will be evaluated with the standard borehole geophysical logging suite.

Groundwater samples will be collected from the mine pool, measured in the field for select inorganic parameters (pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity), and submitted for laboratory analysis of total and dissolved metals and inorganic parameters (see Table 9-1).

9.3.3 Surface Water and Sediment

Previous entities have performed extensive surface water and sediment sampling at the Site and at downgradient streams and wetlands. On-site surface water and sediment samples will be collected for comparison with previous data. In addition, surface water samples will also be collected in the same sampling event as the groundwater samples so that a “snapshot” of groundwater and surface water flux can be produced for each event. The number and location of the surface water samples will be based on the seeps identified during initial screening described in Sections 9.2 and 9.3.

Surface water samples will be measured in the field for select inorganic parameters (pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity) and submitted for laboratory analysis of total and dissolved metals and other inorganic parameters (see Table 9-1).

9.4 Risk Assessments

9.4.1 Human Health Risk Assessment

The prior aquatic investigations performed by USGS (see Section 3.2) in conjunction with site characterization data proposed to be collected in this FIP provides adequate data for the HHRA. At this time, the collection of additional HHRA-specific data is not considered necessary.

9.4.2 Baseline Ecological Risk Assessment

9.4.2.1 Soil

Additional on-site floodplain soil sampling will be performed to characterize overbank sediments and assess potential terrestrial ecological risk (BERA). Surface soil samples

will be collected from two transects to be located across the main on-site tributary stem below the Union Mine waste rock piles in floodplain areas. The exact locations for the floodplain transects may be adjusted during initial Site reconnaissance to ensure that the most appropriate floodplain environment is targeted. A minimum of six samples per transect should be targeted but the exact number of samples collected will be determined by areal extent of floodplain sediments/soils observed. Additional off-site locations may also be necessary. The need to conduct off-site floodplain sampling will be determined based on the initial results of on-site soil and surface water/sediment sampling.

At this time, the collection of other BERA-specific soil samples is not considered necessary. However, some additional analyses are required in addition to the RI characterization data to adequately characterize ecological impacts (i.e. CEC, TOC, and SPLP analysis) as shown in Table 9-1.

9.4.2.2 Surface Water and Sediment

The site characterization data proposed to be collected in this FIP provides adequate on-site and off-site surface water and sediment data for the BERA. At this time, the collection of additional BERA-specific data from on-site locations is not considered necessary. However, some additional sediment analyses are required in addition to the RI characterization data to adequately characterize ecological impacts (i.e. SPLP analysis) as shown in Table 9-1.

9.4.2.3 Vernal Pools

A vernal pool assessment will be performed in accordance with VTDEC guidelines (VTDEC 2003) to identify, map, and characterize the conditions of all vernal pools (i.e. isolated depressional wetlands with no permanent inlet or outlet). The assessment will be conducted in early spring (late April/early May), during which time all vernal pools

located within the on-site EAs will be identified and mapped. All mapped pools will be visited a second time (approx. 4-6 weeks later) to determine if vernal pool characteristics are present. Surface water samples will be collected from each positively identified vernal pool and a qualitative assessment of pool conditions will be determined.

Vernal pool samples will be measured in the field for select inorganic parameters (pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity) and submitted for laboratory analysis of total and dissolved metals and other inorganic parameters (see Table 9-1).

9.4.2.4 Biota

Where habitat conditions are suitable, earthworm samples will be collected and submitted for subsequent contaminant analysis. A minimum of 20 composite invertebrate samples will be collected downgradient of the 4 BERA EAs. An attempt will be made to collect between 5 to 10 background earthworm samples to be co-located with background soil samples.

Where habitat conditions are suitable, small mammal whole-body will be collected for subsequent contaminant analysis. A minimum of 20-30 individual samples will be collected, including 5 per each major waste or tailings pile area. For background small mammal data, prior results collected for the Ely Copper Mine BERA will be used as an appropriate analog.

Biota samples will submitted for laboratory analysis as shown in Table 9-1.

9.5 Other Engineering Investigations

Other data collection activities are required to support both the RI as well as the evaluation of potential remedies for the FS. These are described below.

9.5.1 Water Level Measurements

Synoptic water level measurements will be collected during the same mobilizations as the groundwater sampling, and will include all bedrock and overburden monitoring wells, surface mine pools, and other surface water bodies. The location of all groundwater seeps will be noted, and flow measurements collected where possible from these as well as the surface water weirs.

Long-term and continuous water level measurements are necessary within the underground workings, select monitoring wells, and select perennial surface water locations, along with flow measurements of surface drainage.

Following a review of the well network installation and initial sampling results, several monitoring wells should be selected to be instrumented with continuous water level measurement pressure transducers and monitored for at least 12 months. The wells to be selected should include:

- one well from each identified mine pool;
- up to four wells in the Union/Eureka study area to represent:
 - shallow bedrock in a higher elevation setting (upland);
 - shallow bedrock in a lower elevation setting (lowland);
 - upland deep bedrock; and
 - and lowland deep bedrock.

9.5.2 Hydraulic Conductivity Testing

Hydraulic conductivity testing will be used to determine fate and transport parameters for groundwater. Hydraulic conductivity testing in overburden and shallow bedrock groundwater will consist of rising- and falling-head (i.e. “slug”) tests. A selection of wells considered to be representative of the range of groundwater conditions will be selected for testing; we assume that a total of ten tests will be conducted.

In-well pumping tests (e.g. constant-rate or constant-head) will be conducted at each packer test interval in the deep bedrock monitoring wells, except within wells intercepting the mine pool). If recharge to the well column is insufficient, a modified recovery test will be used instead.

Mine pool water is expected to be impacted at depth at the Eureka and Union mines, given the elevated concentrations of metals in the accessible water at the mine entrances. At these mines (and also the Smith mine, if found to be impacted), a short-term pumping test will be conducted at a bedrock well close to the workings. Samples will be collected over the duration of the test (at minimum, an initial, mid-test, and end of test sample) to see if water characteristic of the mine pool will be drawn into the pumping well.

9.5.3 Surface Water Gauges

Surface water gauges or other permanent survey locations will be added to the mine pool entrances (if deemed acceptable based on the sensitive receptor survey described in Section 9.2.5) and other locations with ponded water.

9.5.4 Geotechnical Sampling

Geotechnical samples will be collected along with the chemical characterization samples described in Section 9.4 to minimize the number of mobilizations required. Geotechnical samples will be collected for both native soil and waste material, and will be used to support development of remedial alternatives in the FS. The SPT results described in Section 9.5.1 and the hydraulic conductivity testing described in 9.5.2 will also be used to determine geotechnical parameters.

Geotechnical samples will include grain size analysis, but may also include other parameters (e.g. Atterberg, etc.).

9.5.5 Vibration Monitoring

A vibration study may be used to evaluate the magnitude of vibration associated with investigation and remedial activities (e.g. heavy equipment, drilling) and to assess to potential impacts of those vibrations on both mine features and the local bat population. The results of the vibration monitoring may be used to determine the need to establish safe zones, both vertical and lateral, from the workings. Vibration monitoring would include surface seismographs and may also include installation of geophones in bedrock boreholes installed close to the workings.

9.5.6 Groundwater/Surface Water Interactions

Detailed flow measurements and the seasonal changes of these flows within the site watershed will be required to develop an accurate hydrologic model for the RI (i.e. quantify the bedrock yield and base flow; quantify the volumetric discharge rates from the underground workings and on-site tributaries; evaluate the seasonal fluctuations and maximum flows into and from the underground workings and on-site drainage system).

9.5.6.1 Flow Measurements

Three flow measurement stations will be constructed. At each of the flow measurement stations flow-calibrated V-notch weirs or Parshall flumes will be installed, depending upon the likelihood of the measurement station to accrete sedimentary or organic obstructions. A preliminary analysis of flow will be conducted prior to weir installation to determine the appropriate V-notch weir or Parshall flume sizing. Field/flow measurements will be collected over a 12-month period to establish baseline and peak flow data and surface water elevation. Flow calibrations will be verified periodically utilizing a graduated 5-gallon bucket, or appropriate-sized container as flow dictates, and stopwatch to measure flow rate. A corresponding surface water elevation and head will be recorded at the time of collection of flow data. Flow measurements will be taken during Spring thaw (e.g. March/April), during a sustained low flow condition (e.g. July/August), and during a sustained wet period (e.g. September/October). Additional flow measurements will be collected during Site visits conducted for other purposes (e.g. drilling, soil sampling, groundwater monitoring).

9.5.6.2 Hydrologic Modeling

Hydrologic Modeling will be performed on water bodies to evaluate flow through (drainage area), as well as ponds and major wetlands. The purpose of the hydrologic model is to:

- Characterize storm runoff (peak/volume/quality)
- Determine the effects of watershed basin changes
- Determine the effects of control options
- Perform frequency analysis
- Provide input to other models (stormwater)

The required data is similar to what is required for stormwater modeling, but on a larger scale with more of a focus on open channel flow and flooding. Available USGS topographic data and geographical information system (GIS) coverages will be used to divide the site into critical sub-basins to evaluate where specific information is needed (i.e. at tributaries, major storage units, and major structural changes). Data required to develop the model includes the flow and elevation/field survey data noted above, but also includes soil information, ground cover conditions, rainfall data, and familiarity with the site.

Available published flood data/studies will be gathered, if available, and utilized in development of the model. In the absence of published data, historical evidence of flood information will be gathered during site reconnaissance including physical evidence (bridges, markers, signs) and oral accounts from local officials and residents in the area.

Once published data is evaluated, a two-day site reconnaissance will be conducted by an experienced hydrologic engineer to evaluate actual field conditions and drainage patterns of the watershed. During the site reconnaissance, the following details will be evaluated and documented with pictures and field notes:

- Streambed, floodplain and overbank characteristics of (drainage) and tributaries (vegetation, slopes/falls, and bed geology);
- Major structural changes/controls in the waterways (beaver dams, culverts, bridges, deadfalls, and other obstructions);
- Changes in streambed flow characteristics (slopes, falls, pools, meanders);
- General characteristics of the watershed and sub-basins.

Further field reconnaissance may be required once an initial model is prepared and calibrated to verify data, and collect additional information, if required. This would may include a one to two day site visit.

9.5.7 Failure Mode Effects Analysis

The FMEA for the initial field investigation is included as Appendix X (SLR, 2018). The FMEA will be updated as new data are available and the risk estimates are refined. The focus of the FMEA was to identify the failure modes that could contribute to a sudden, uncontrolled release of mining impacted water (MIW) from the mine underground workings in excess of the ability of the infrastructure available at the site to contain and treat the discharge. The FMEA considered only one phase the timeframe for current conditions and investigation (assumed to up to 5 years in duration). The FMEA established a likelihood scale and a consequence scale based on the probability of occurrence of the failure modes identified and their associated consequences. For each failure mode, a corrective action, remediation, or mitigation measures have been suggested and the risk re-evaluated for each failure mode assuming implementation of those measures.

The FMEA identified one dominant failure mode at each mine:

- **Smith Hill Mine Failure Mode S1b:** This failure mode is associated with the formation of a blockage in the Smith Adit, regardless of its origin, and its subsequent catastrophic failure. Failure Mode S1b would result in the sudden and uncontrolled release of up to 205,000 gallons of MIW under approximately 60 ft of pressure head, potentially causing erosion, scouring, and damage to site features such as the waste rock piles, roads, and surface water of the Waits Watershed. Visual, chemical, and physical impacts to water quality of the Waits Watershed water bodies would be observed. Mitigation measures to reduce the risks associated with Failure Mode S1b are suggested in the FMEA calculations included in Appendix B and the resulting risk for Failure Mode S1b was

recalculated assuming mitigation measures were applied). The results demonstrate that mitigation measures could reduce the RPN for Failure Mode S1b from 90 (“Orange Zone”) to 30 (“Green Zone”).

- Union Mine Failure Mode U1b: This failure mode is associated with the formation of a blockage in the Union Adit, regardless of its origin, and its subsequent catastrophic failure. Failure Mode U1b would result in the sudden and uncontrolled release of up to 365,000 gallons of MIW under approximately 40 ft of pressure head, potentially causing erosion, scouring, and damage to site features such as the waste rock piles, roads, and surface water of the Waits Watershed. Visual, chemical, and physical impacts to water quality of the Waits Watershed water bodies would be observed. Mitigation measures to reduce the risks associated with Failure Mode U1b are suggested in the FMEA calculations included in Appendix B. The resulting risk for Failure Mode U1b was recalculated assuming that one of the mitigation measures was applied. The results show the RPN for Failure Mode U1b drop from 90 to 30.
- Eureka Mine Failure Mode E1a: This failure mode is associated with the formation of a blockage in the Eureka Lower Adit, regardless of its origin, and its subsequent catastrophic failure. Failure Mode E1a would result in the sudden and uncontrolled release of up to 480,000 gallons of adit discharge water under approximately 30 ft of pressure head, potentially causing significant erosion, scouring, and damage to site features such as the waste rock piles, roads, and surface water of the Waits Watershed. Visual, chemical, and physical impacts to water quality of the Waits Watershed water bodies would be observed. Mitigation measures to reduce the risks associated with Failure Mode E1a are suggested in the FMEA calculations included in Appendix A. The resulting risk for Failure Mode E1a was recalculated assuming that mitigation measures were applied. The results show that some mitigation or corrective measure could reduce the RPN for Failure Mode E1a from 90 to 30.

10.0 SITE MANAGEMENT, ACCESS, AND SEQUENCING OF ACTIVITIES

In order to complete Site activities in a timely and cost-effective manner, Site access and the sequencing of field activities must be evaluated. Due to the limited road access, steep terrain, and limited areas for staging, careful coordination will be needed to ensure the smooth and safe implementation of the various phases of Site activities. The steep terrain and safety concerns regarding the stability of waste piles and underground workings must be evaluated to determine the most feasible approach. The anticipated relative sequence of data collection activities is outlined below. The actual sequence may be revised as dictated by funding requirements.

Phase I

- site reconnaissance, ground-based survey, and LiDAR survey;
- hydrologic and soil conditions field reconnaissance;
- access road upgrades and installations;
- bedrock outcrop structural survey;
- sensitive receptor surveys;
- floodplain pool mapping;
- vernal pool mapping;
- surface weir/flume construction;
- sediment and surface water sampling, and
- surface soil sampling program.

Phase II

- Subsurface soil sampling program, well installations, and vibration study;
- groundwater sampling;
- initiation of water level measurement/flow monitoring program.

Phase III

- Drilling program to intercept and sample mine pools;
- Continuation of water level measurement/flow monitoring program.

Field sampling and data collection activities at on-site areas must be coordinated to minimize Site disturbance and utilize existing access roads wherever possible. Site activities must be conducted in such a way as to respect the conditions of access agreements with property owners. In addition, due to the historical significance of Site features, a historical resource specialist will be consulted prior to intrusive or other Site activities that might disturb Site features or the landscape to obtain concurrence on the approach. As necessary, photo documentation by a certified professional will be used to document Site conditions, assist in determining the best approach to gathering data while limiting Site disturbance, and appropriate restoration. Boring and monitoring well locations will be moved as necessary to optimize data collection and Site preservation.

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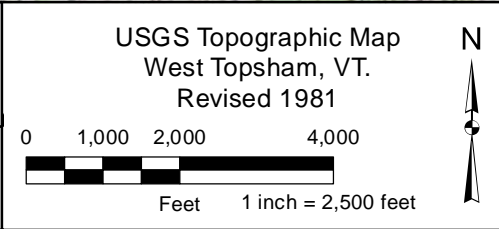
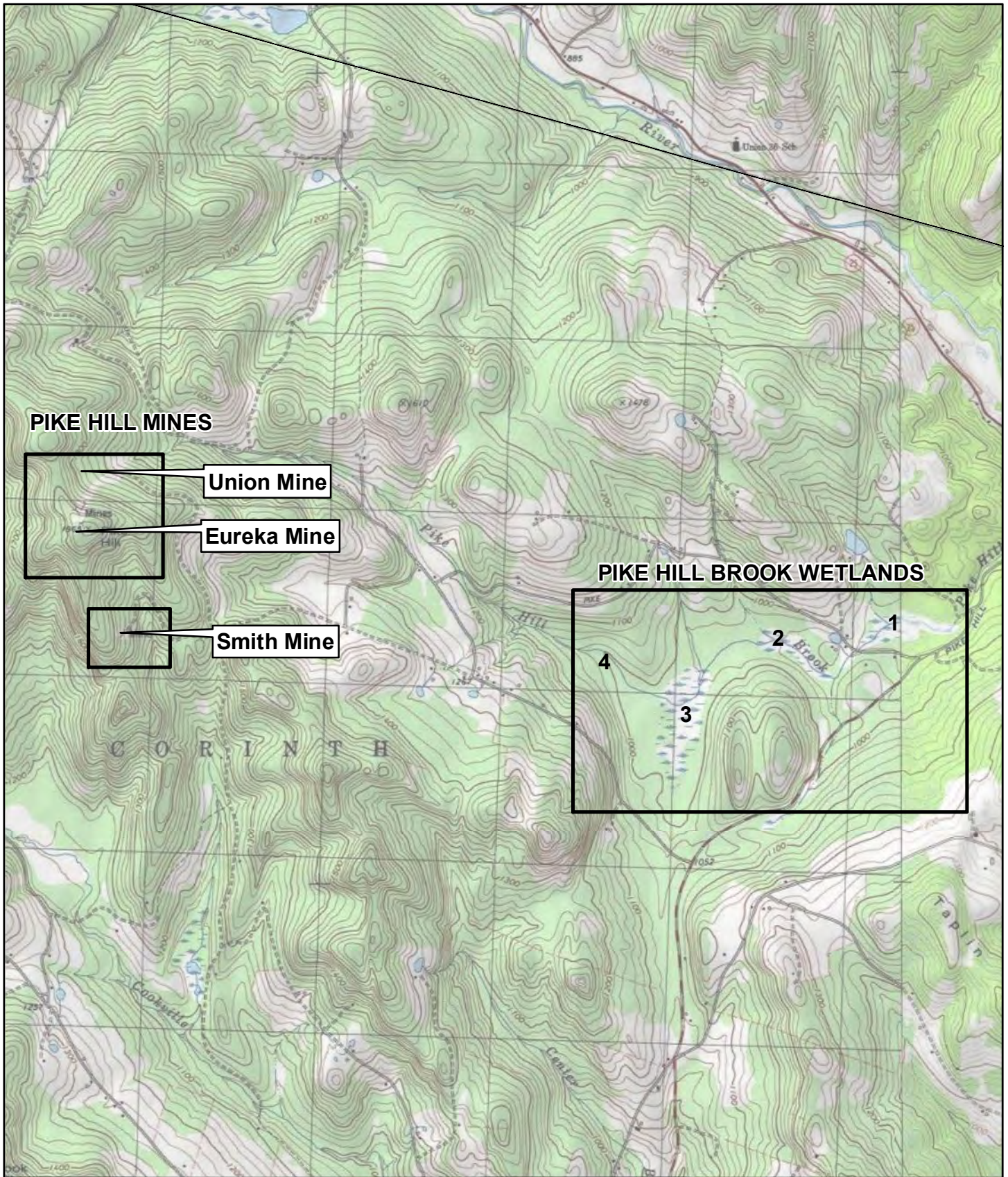
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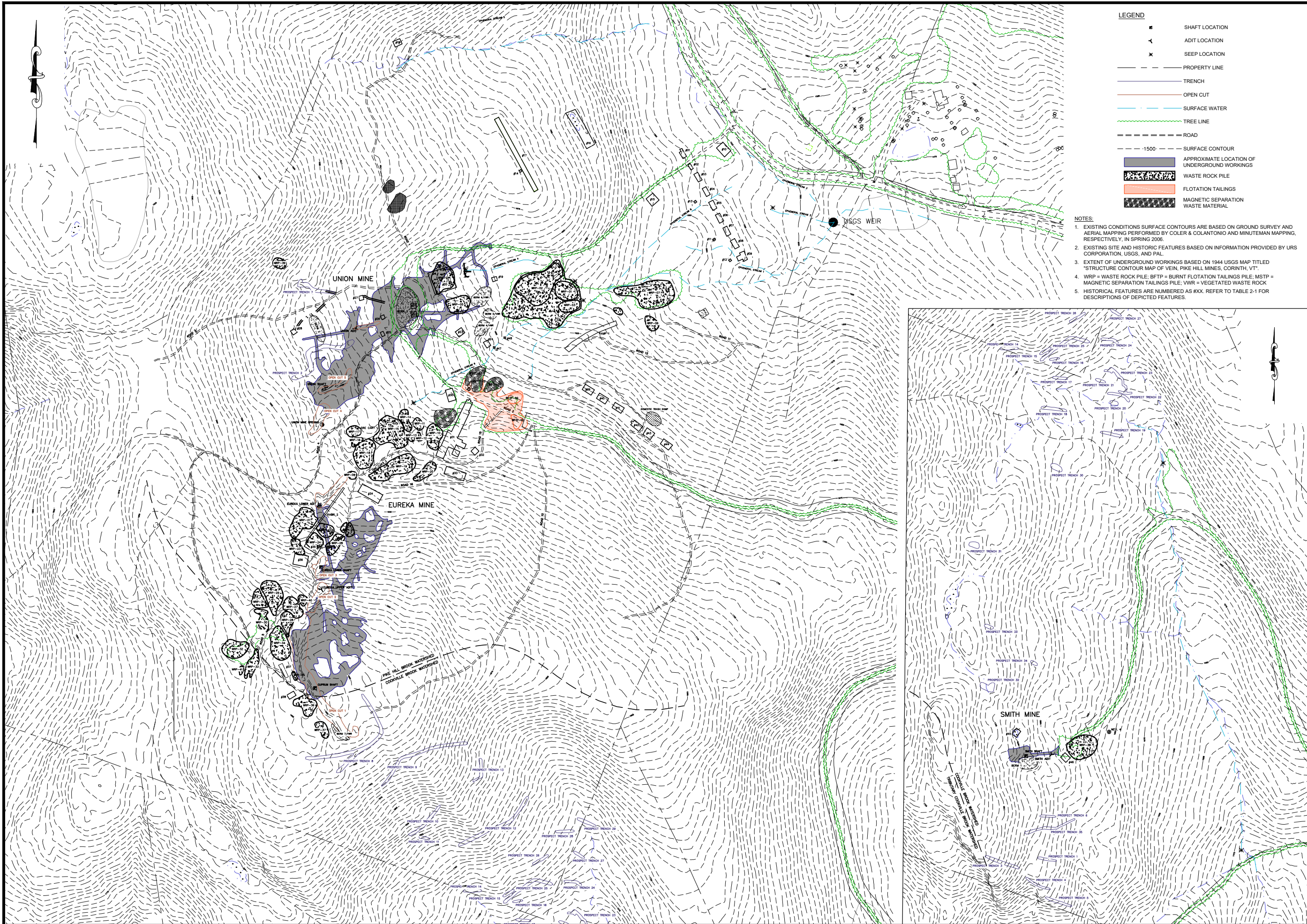
FIGURES



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FIGURE 2-1	
SITE LOCUS PIKE HILL COPPER MINE SUPERFUND SITE CORINTH, VERMONT	
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PROJECT NO. 80111	DATE: APRIL 2017

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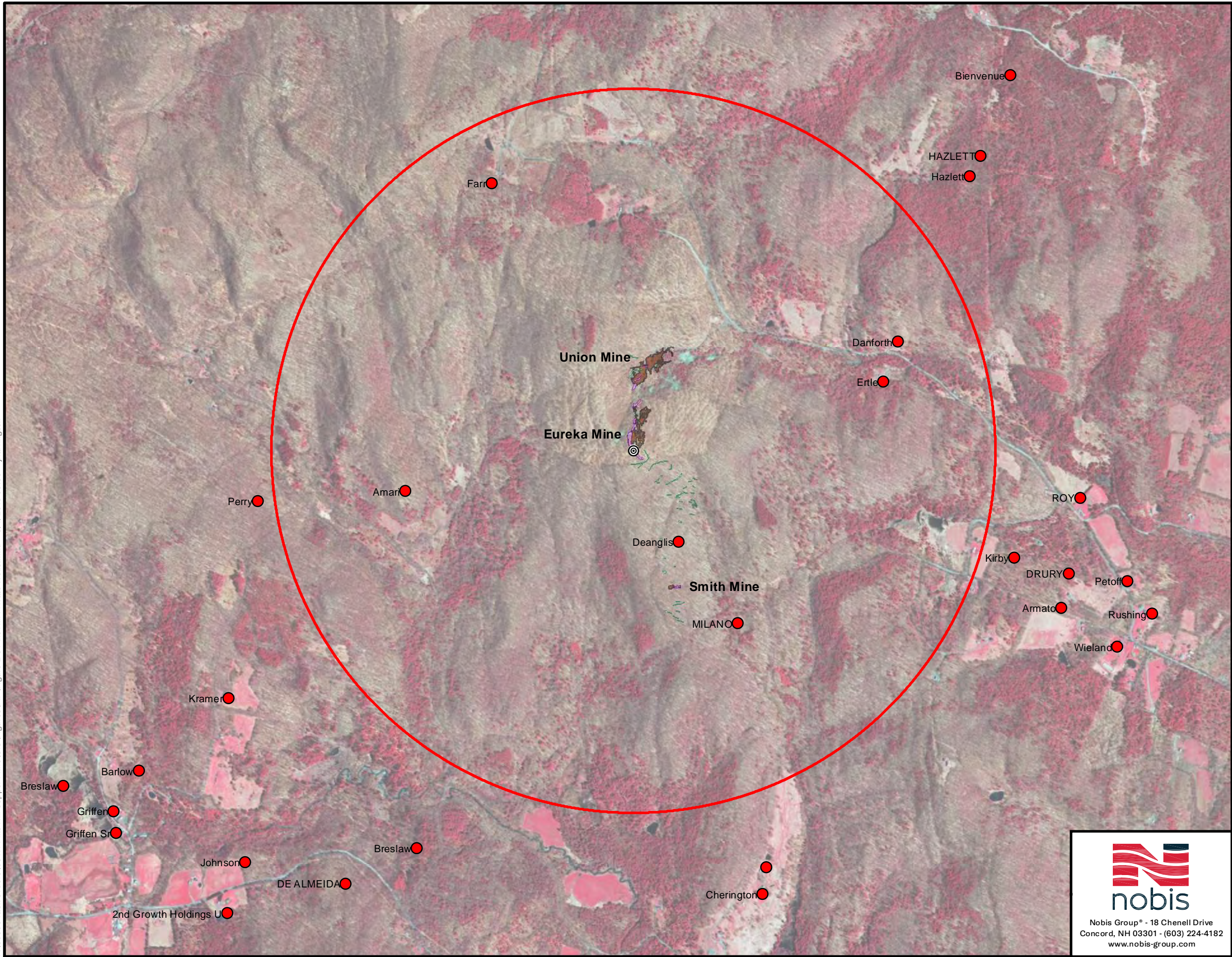
PIKE HILL COPPER MINES
SUPERFUND SITE
CORINTH, VERMONT

NO.	DATE	DESCRIPTION
REVISIONS		
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GRAPHIC SCALE		
DATE: FEBRUARY 2017		
NOBIS PROJECT NO. 80111.01		
DRAWN BY: BJK		
CHECKED BY: AB		
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SHEET TITLE		

SITE SKETCH

**FIGURE
2-2**

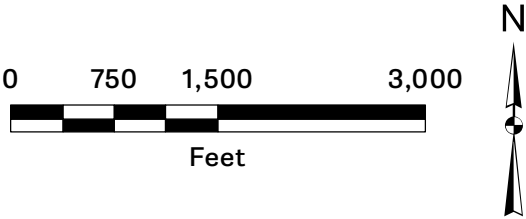
F:\80000 Task Orders\80111 Pike Hill Copper Mine\GIS\Figures\FIP\Figure 2-5 Pike Hill Private Wells.mxd 8/1/2019 09:09 jharrington




- Notes:**
1. Sources: Strategic Minerals Investigations, Preliminary Map Plates 7 and 8, USGS, 1944. Private Wells from VTANR Open Data: <http://gis.vtanr.opendata.arcgis.com/> revised 2015.
 2. The nearest public water source is approximately 3 miles northeast of Eureka Mine.
 3. Aerial photography from Vermont Open Data Portal, 2011.
 4. Locations of site features depicted hereon are approximate and given for illustrative purposes

Legend

- Private Wells
- One Mile Radius from South of Eureka Mine Workings
- Underground Workings
- Open Cut
- Trench



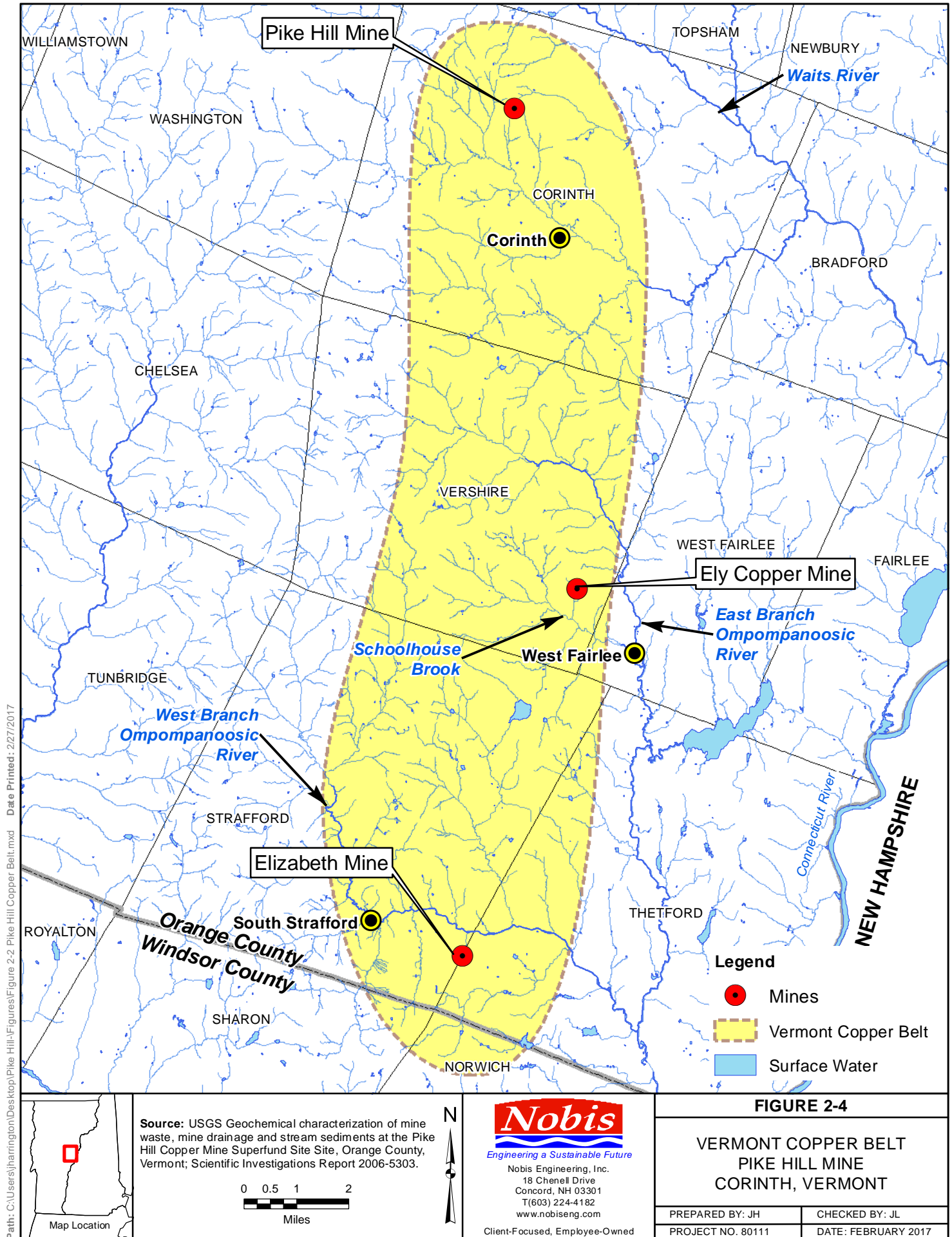


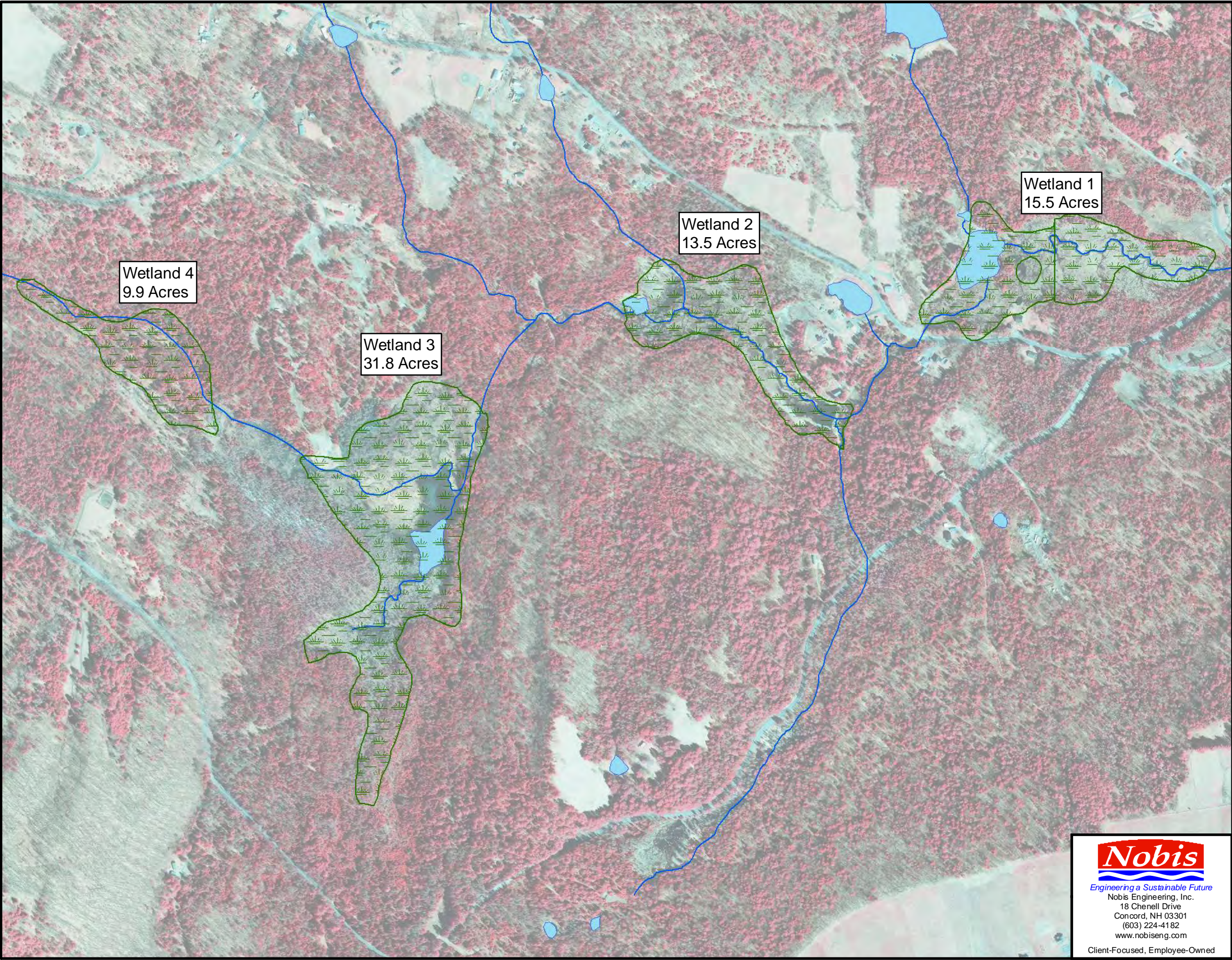
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FIGURE 2-3

**PRIVATE WATER SUPPLY WELLS
PIKE HILL MINE
CORINTH, VERMONT**

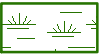


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PROJECT NO. 80111	DATE: AUGUST 2019

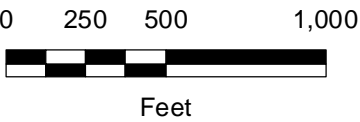




- Notes:**
1. Wetlands obtained from Vermont Open Geodata Portal, originated by U.S. Fish & Wildlife Service National Wetlands Inventory, revised 1983. Streams & surface water bodies obtained from Vermont Open Geodata Portal, originated by U.S Geological Survey/Environmental Protection Agency, revised 1999.
 2. Aerial photography from Vermont Open Data Portal, 2011.
 3. Locations of site features depicted hereon are approximate and given for illustrative purposes only.

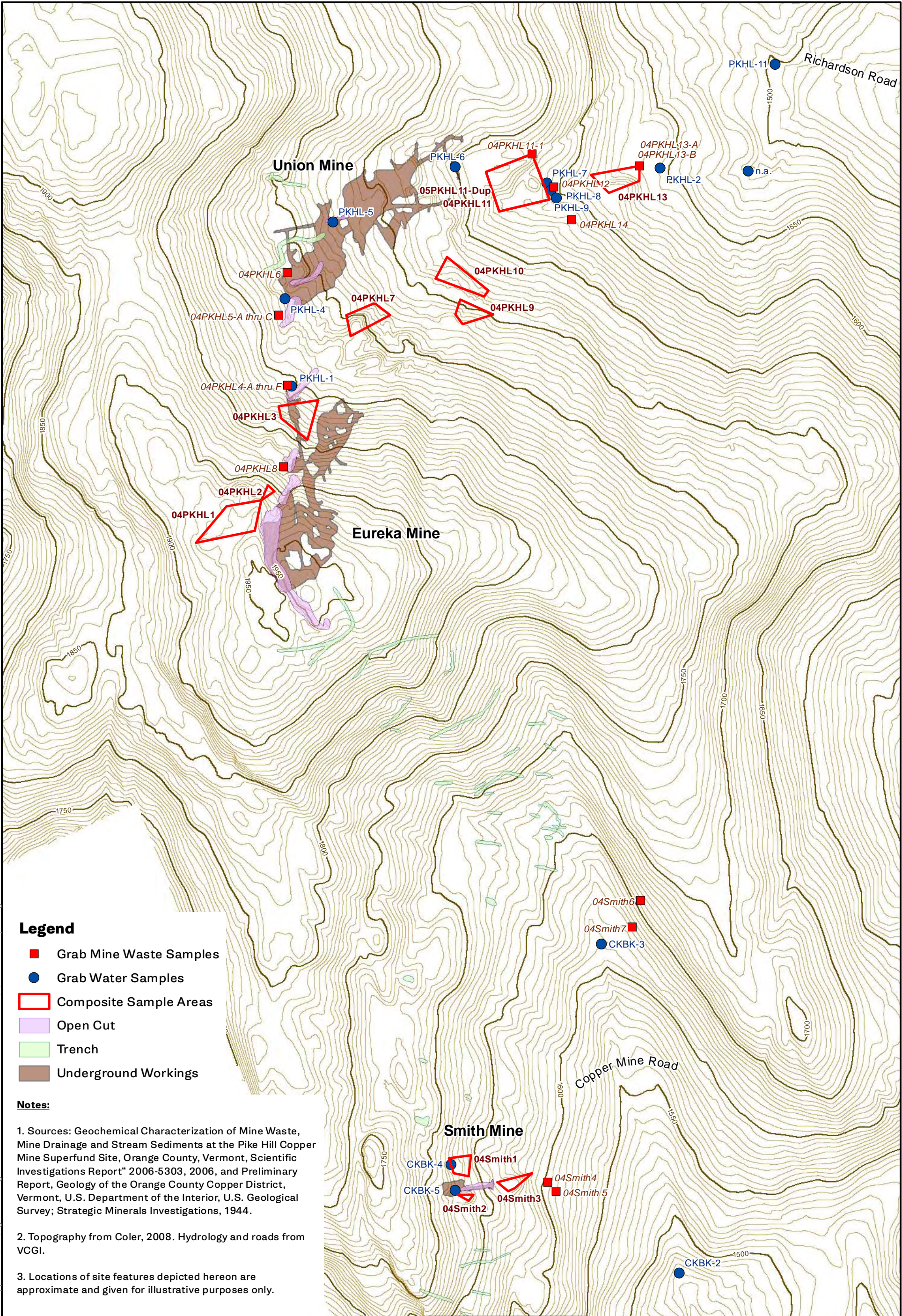
Legend

-  Wetlands
-  Surface Water Bodies
-  Streams



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FIGURE 2-5	
PIKE HILL BROOK WETLAND COMPLEX PIKE HILL MINE CORINTH, VERMONT	
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PROJECT NO. 80111	DATE: FEBRUARY 2017



0 150 300 600
Feet
1 inch = 300 feet



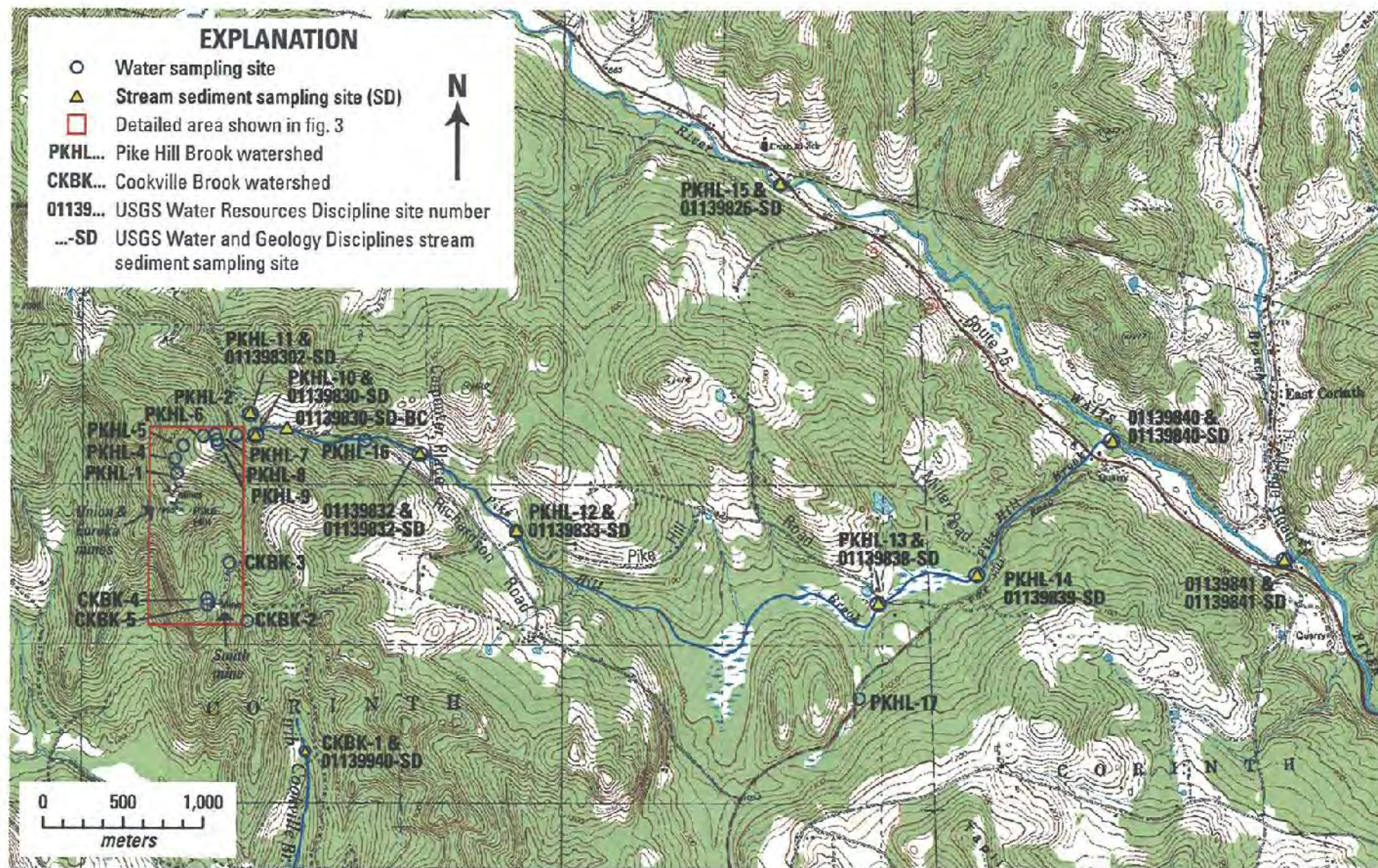
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FIGURE 3-1

PREVIOUS SURFACE SOIL AND
WASTE ROCK LOCATIONS
PIKE HILL MINE
CORINTH, VERMONT

PREPARED BY: JH
PROJECT NO. 80111

CHECKED BY: JK
DATE: AUGUST 2019



Notes:

1. This figure was developed from information found within the "USGS Geochemical Characterization of Mine Waste, Mine Drainage, and Stream Sediments at the Pike Hill Copper Mine Superfund Site Site, Orange County, Vermont: Scientific investigations report 2006-5303".



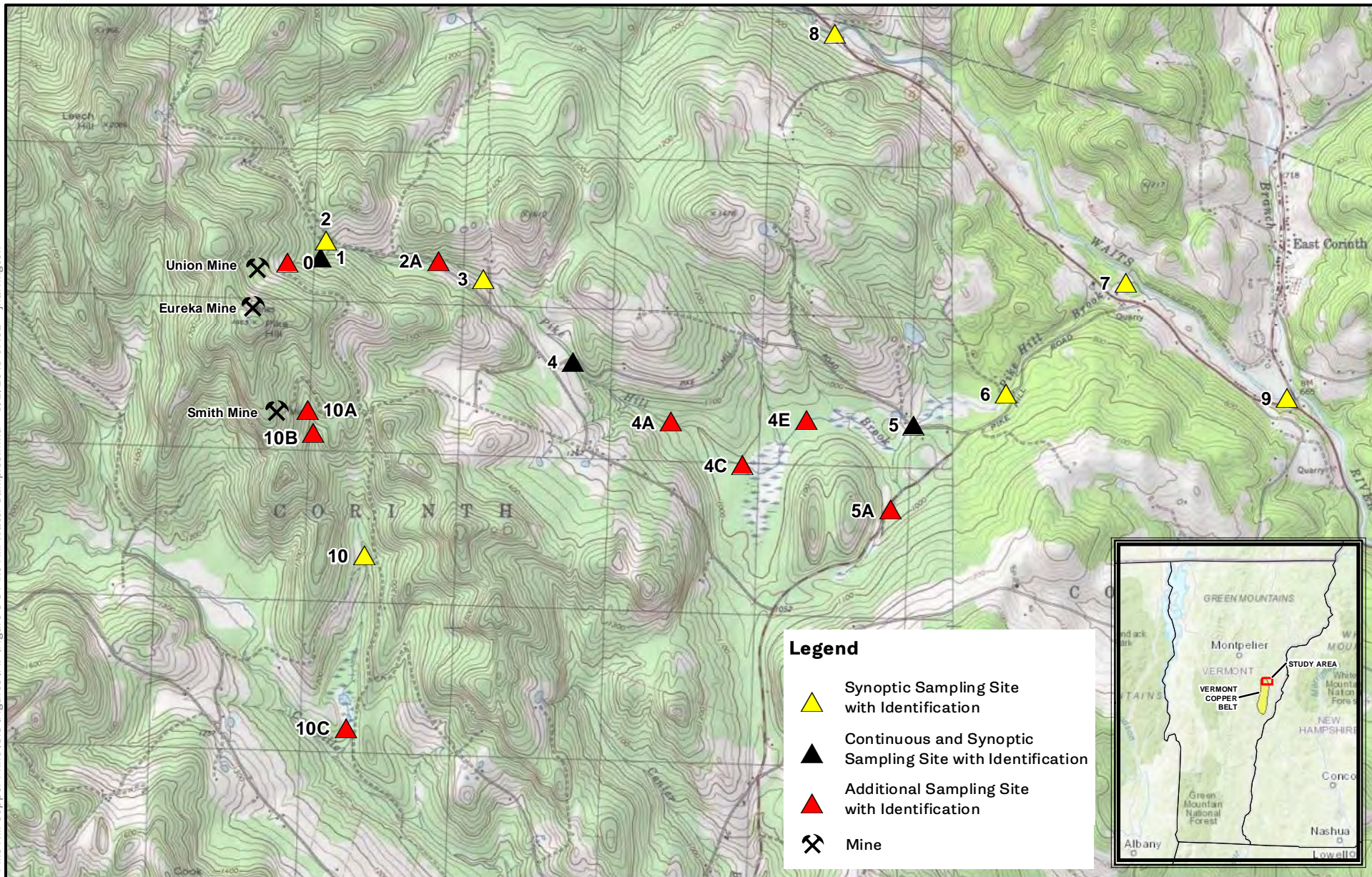
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FIGURE 3-2

USGS SURFACE WATER AND
 SEDIMENT SAMPLE LOCATIONS
 PIKE HILL COPPER MINE SUPERFUND SITE
 CORINTH, VERMONT

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FIGURE 3-3

**WATER SAMPLING SITE LOCATIONS
PIKE HILL COPPER MINE
SUPERFUND SITE
CORINTH, VERMONT**

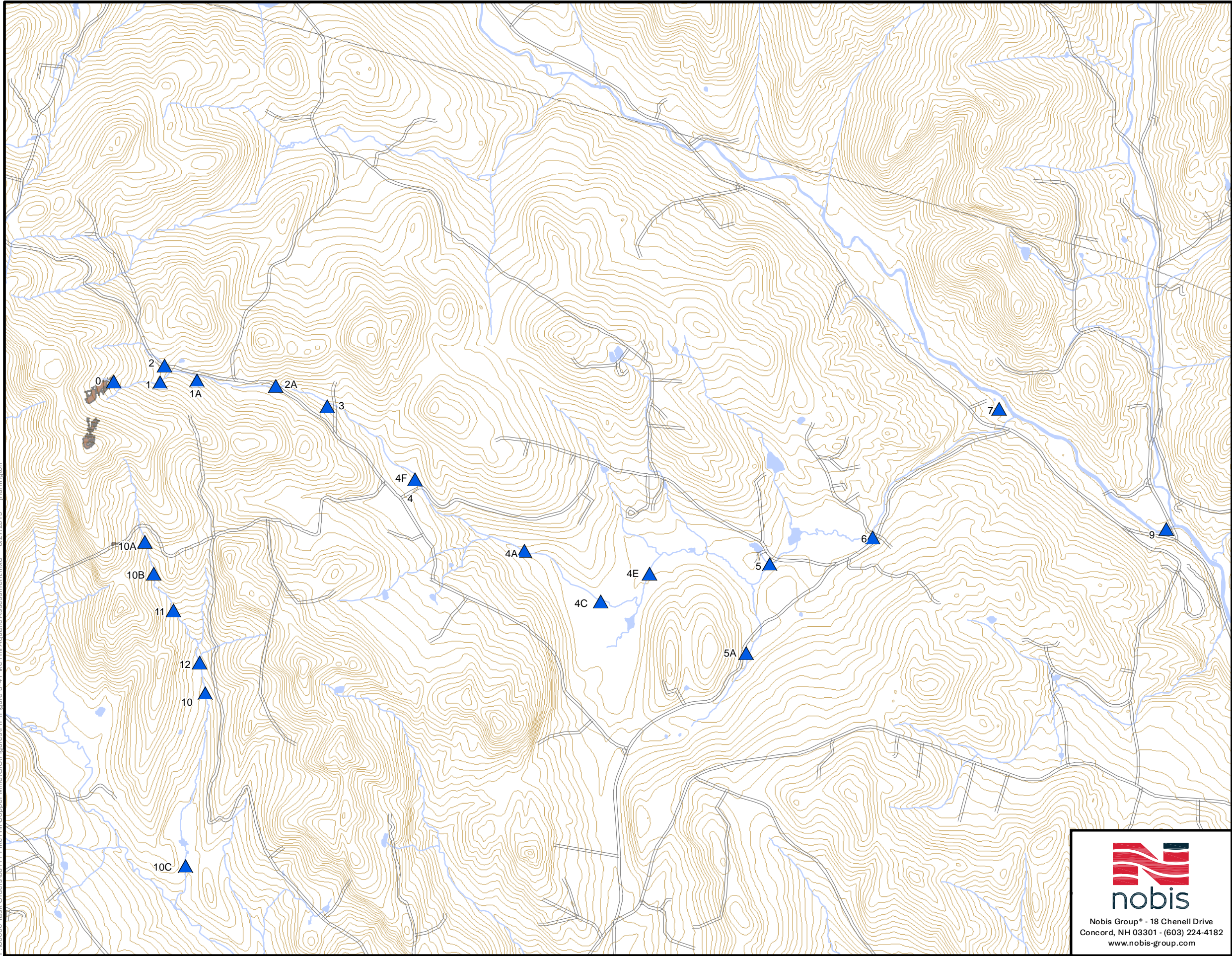
PREPARED BY: JH

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PROJECT NO. 80111

DATE: AUGUST 2019

F:\90000 Task Orders\90111 Pike Hill Copper Mine\GIS\Figures\Figure 3-4 Pike Hill Aquatic Assessment.mxd 8/27/2019 jharington



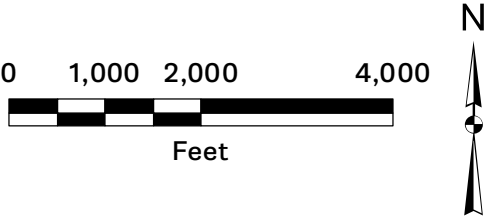
- Notes:**
1. Source: Aquatic Assessment of the Pike Hill Copper Mine Superfund Site, Corinth, Vermont; USGS Scientific Investigations Report 2012-5288. 2012.
 2. Topography from Coler, 2008. Hydrology and roads from VCGI.
 3. Locations of site features depicted hereon are approximate and given for illustrative purposes only.

Legend

Surface Water Samples

▲ Surface Water Samples

■ Underground Workings




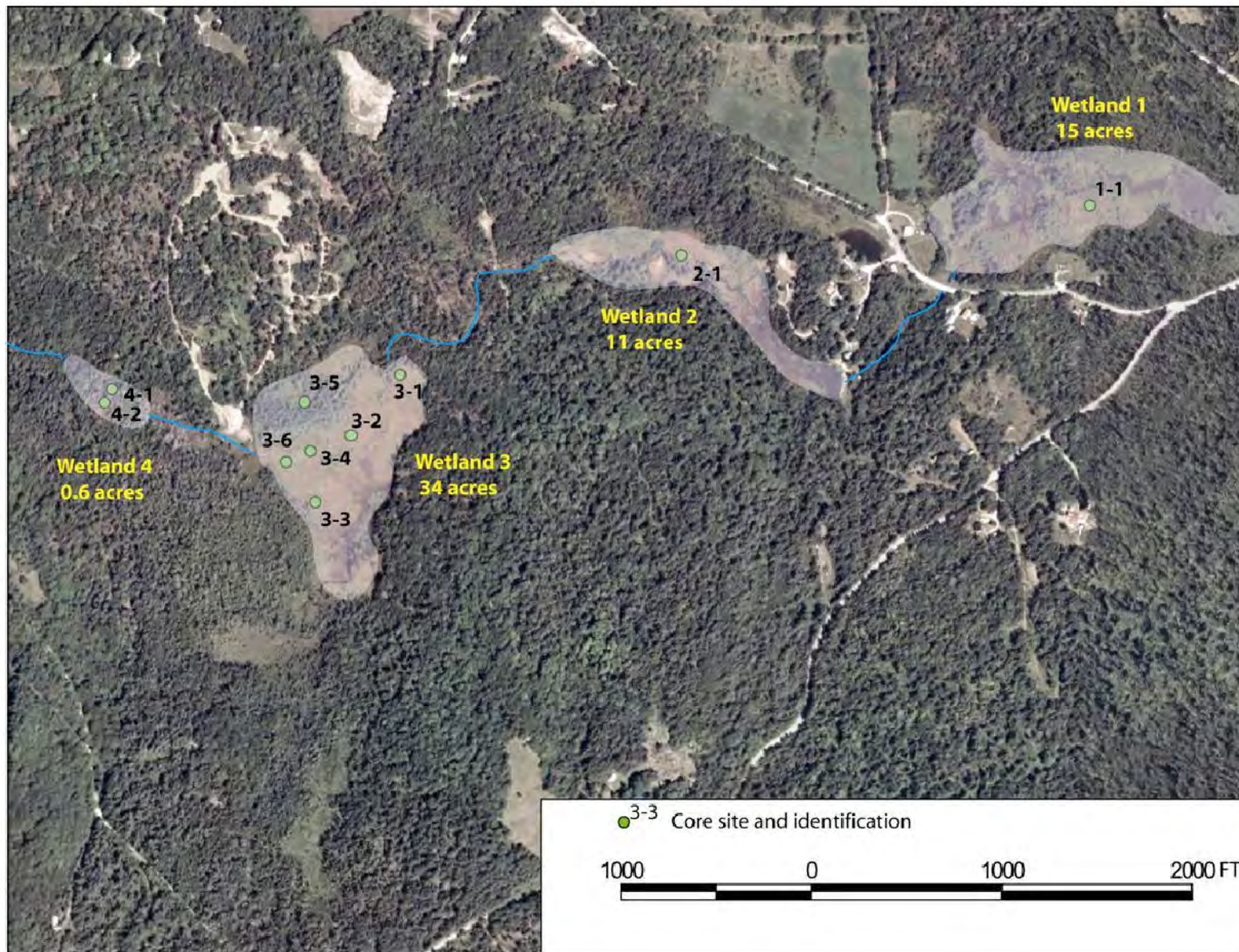

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FIGURE 3-4	
USGS AQUATIC ASSESSMENT (PIKE HILL MINE CORINTH, VERMONT	
PREPARED BY: JH	CHECKED BY: AB
PROJECT NO. 80111	DATE: AUGUST 2019



Notes:

1. Source: Aquatic Assessment of the Pike Hill Copper Mine Superfund Site, Corinth, Vermont; USGS Scientific Investigations Report 2012-5288. 2012.



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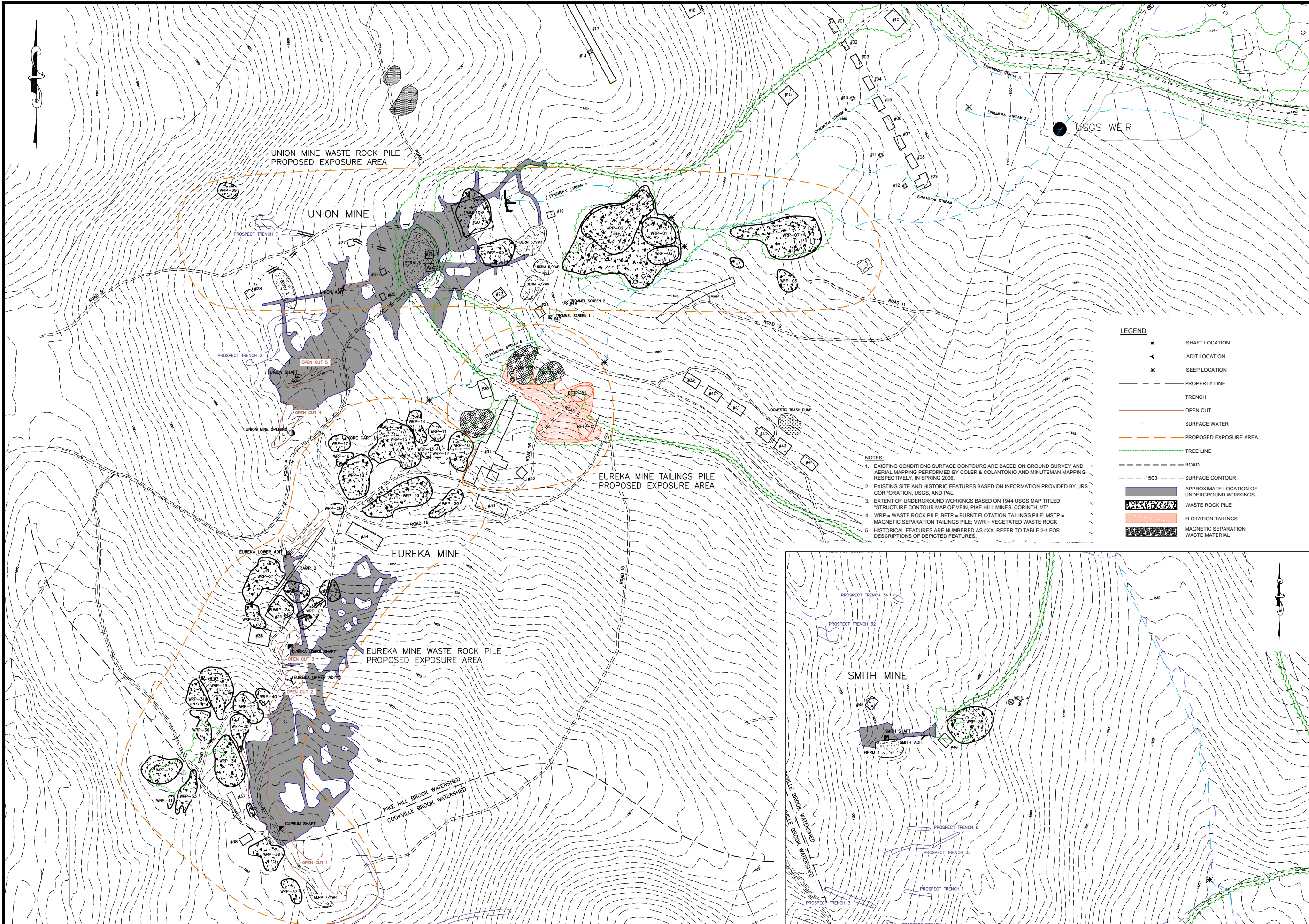
FIGURE 3-5

USGS WETLAND COMPLEX SAMPLES
(
PIKE HILL COPPER MINE SUPERFUND SITE
CORINTH, VERMONT

PREPARED BY: JH
PROJECT NO. 80111

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PIKE HILL COPPER
MINES

SUPERFUND SITE
CORINTH, VERMONT

NO.	DATE	DESCRIPTION
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GRAPHIC SCALE

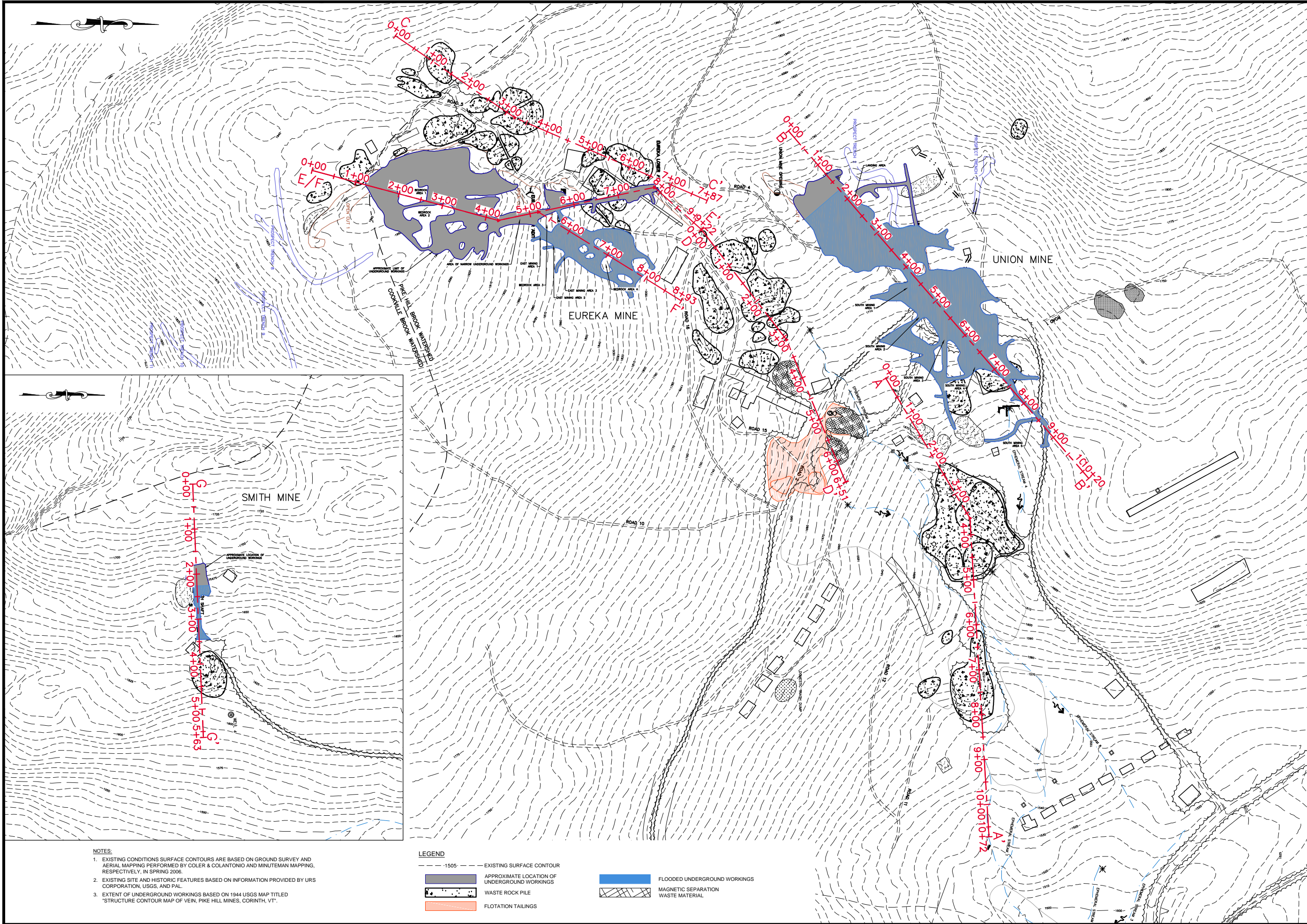
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PROPOSED
EXPOSURE
AREAS

FIGURE
4-1

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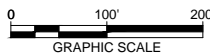
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PIKE HILL COPPER MINES

SUPERFUND SITE
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NO.	DATE	DESCRIPTION
REVISIONS		

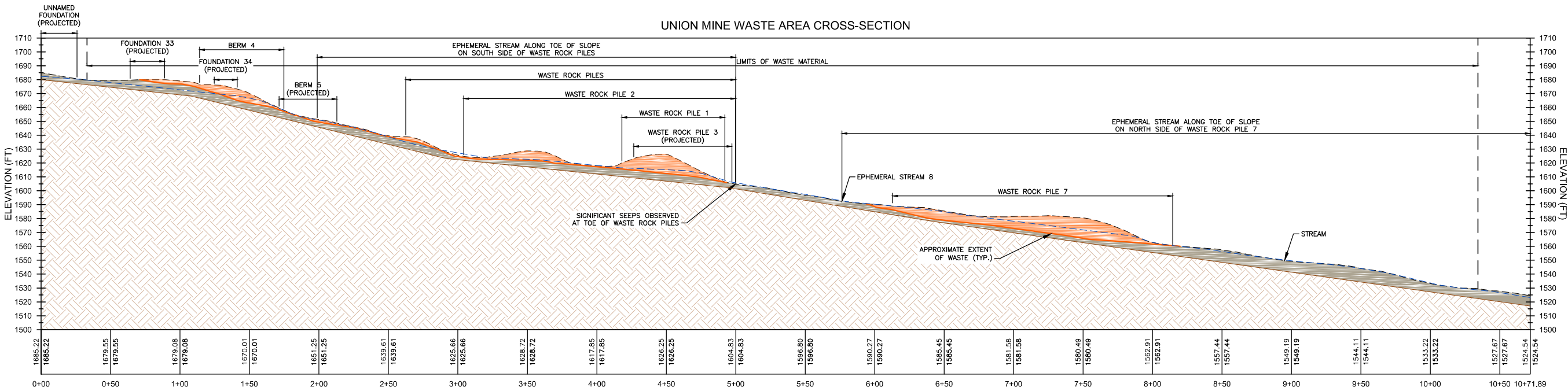


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CROSS-SECTION LOCATIONS

FIGURE
4-2

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- NOTES:**
1. EXISTING CONDITIONS SURFACE CONTOURS ARE BASED ON GROUND SURVEY AND AERIAL MAPPING PERFORMED BY COLER & COLANTONIO AND MINUTEMAN MAPPING, RESPECTIVELY, IN SPRING 2006.
 2. EXISTING SITE AND HISTORIC FEATURES BASED ON INFORMATION PROVIDED BY URS CORPORATION, USGS, AND PAL.
 3. EXTENT OF UNDERGROUND WORKINGS BASED ON HISTORIC INFORMATION AND ASSUMPTIONS.
 4. REFER TO FIGURE 4-2 FOR PLAN VIEW AND LOCATION OF ALIGNMENT.

LEGEND	
---	EXISTING GROUND SURFACE
---	INFERRED OVERBURDEN GROUNDWATER LEVEL
---	INFERRED BEDROCK GROUNDWATER LEVEL
---	INFERRED BEDROCK SURFACE
	WASTE MATERIAL
	UNMINED BEDROCK AREA
	OVERBURDEN (NATIVE SOIL)



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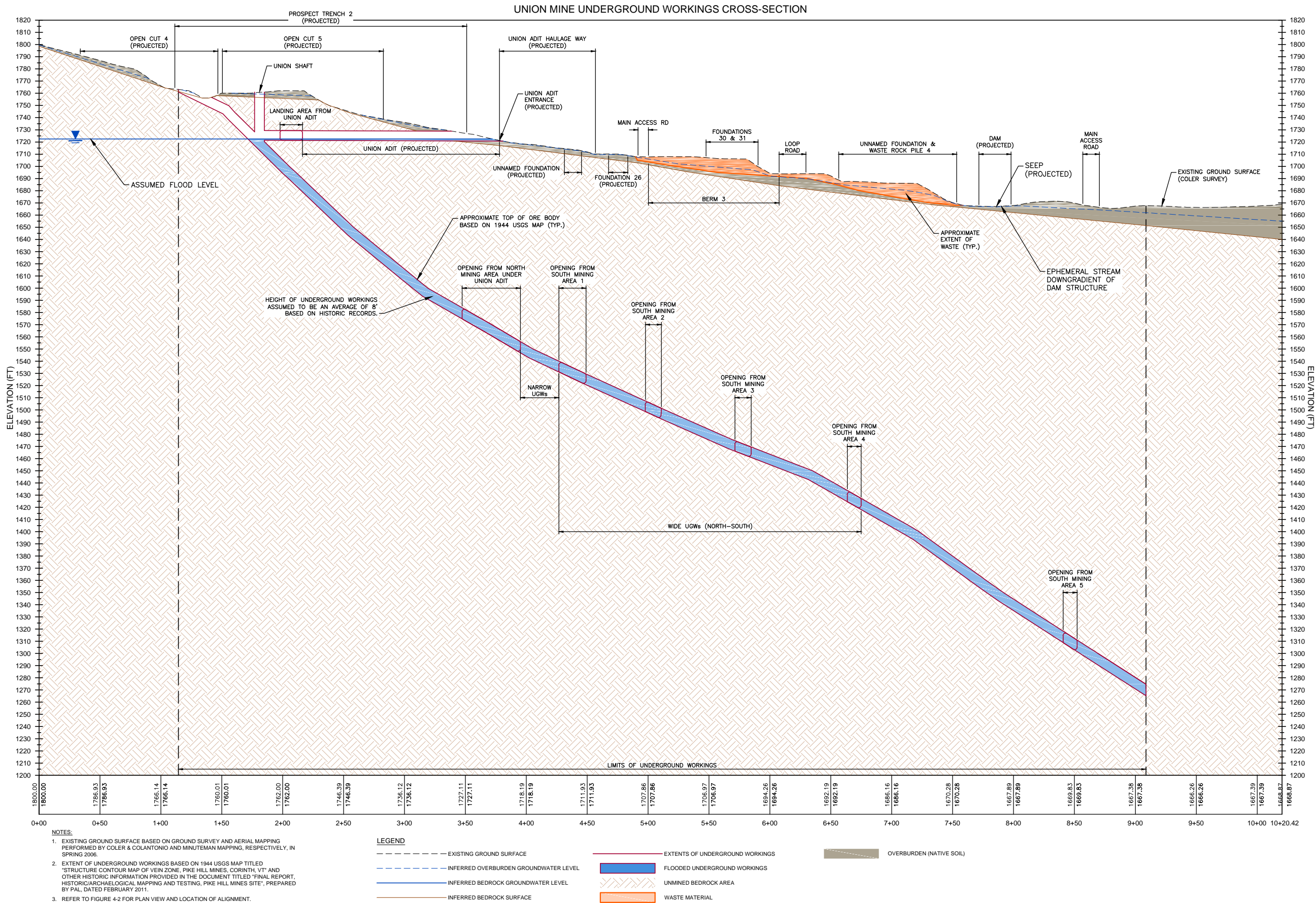
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CROSS-SECTION A-A'
UNION MINE
WASTE AREA

FIGURE
4-3

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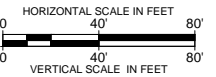


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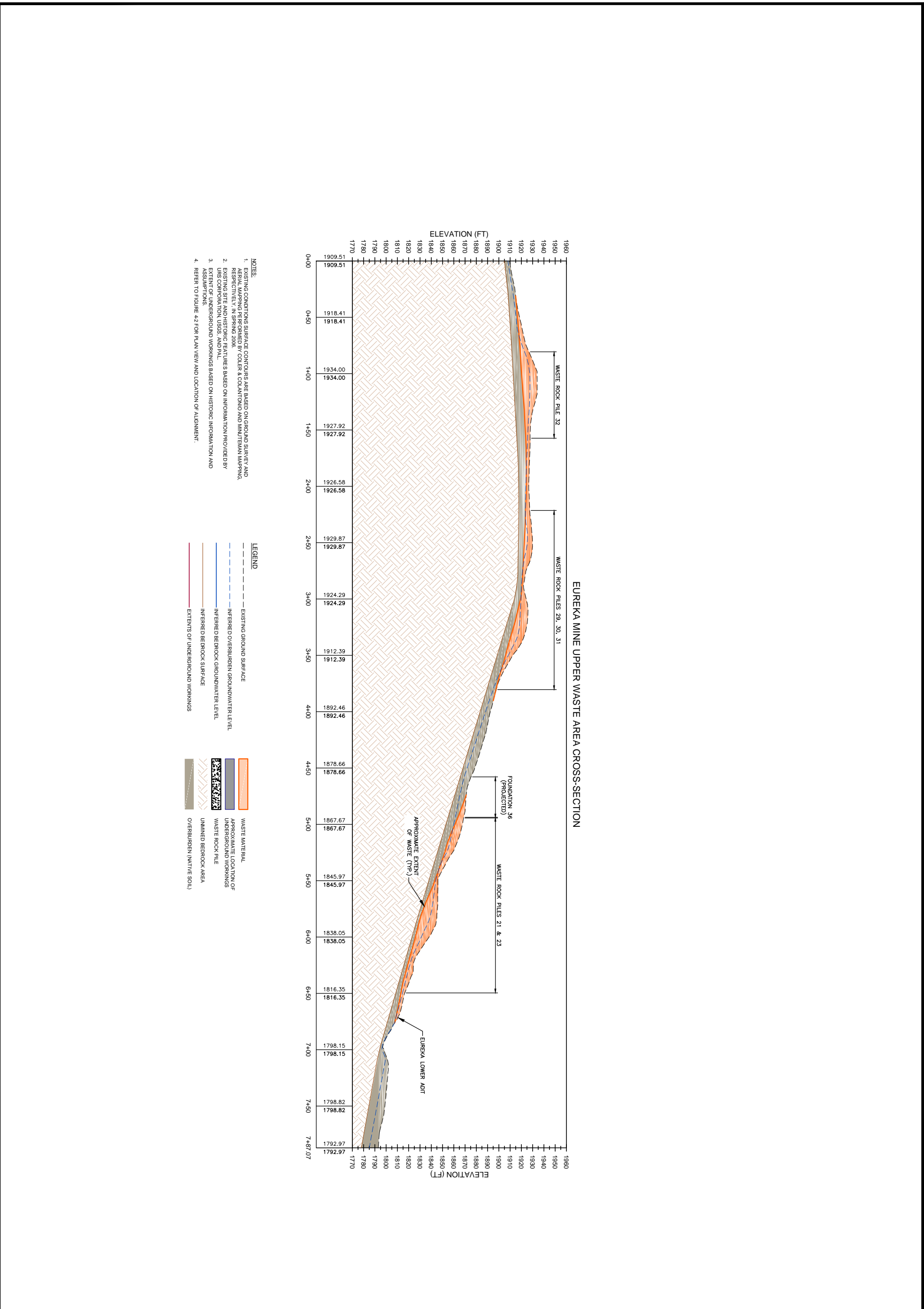


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**CROSS-SECTION B-B'
UNION MINE
UNDERGROUND
WORKINGS**

**FIGURE
4-4**



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CROSS-SECTION C-C'
EUREKA MINE
WASTE AREA 1

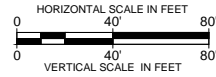
FIGURE
4-5A

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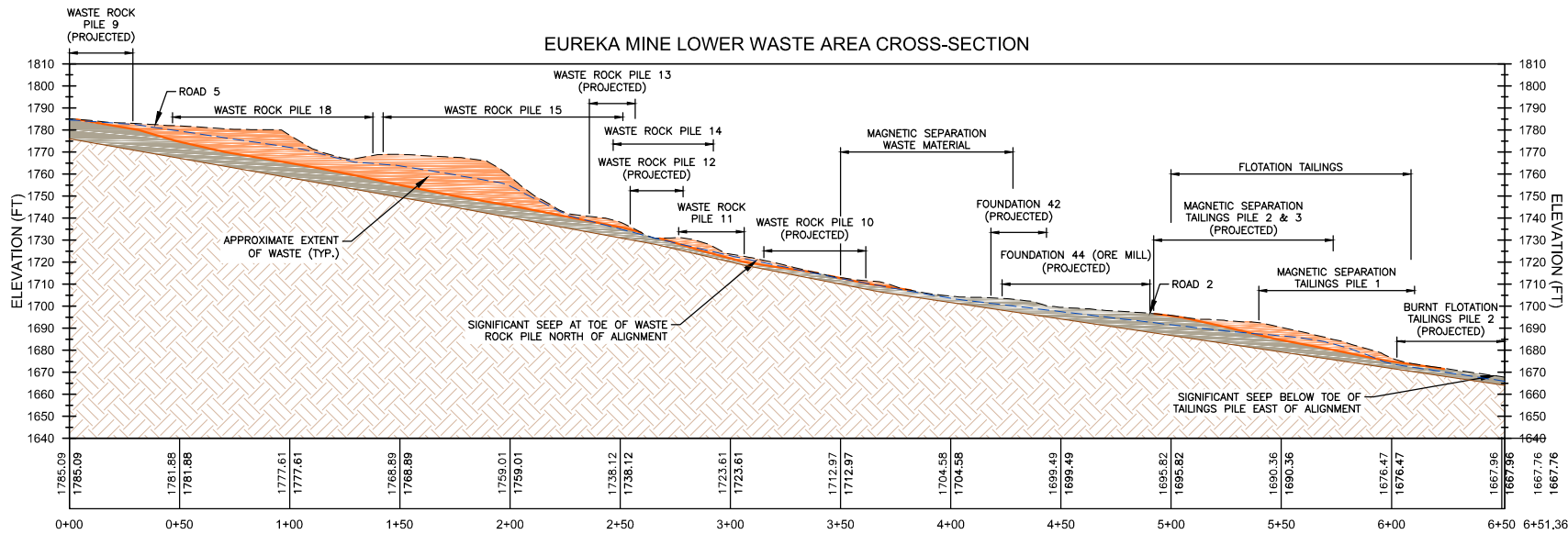
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CROSS-SECTION D-D'
EUREKA MINE
WASTE AREA 2

FIGURE
4-5B



- NOTES:
- EXISTING CONDITIONS SURFACE CONTOURS ARE BASED ON GROUND SURVEY AND AERIAL MAPPING PERFORMED BY COLER & COLANTONIO AND MINUTEMAN MAPPING, RESPECTIVELY, IN SPRING 2006.
 - EXISTING SITE AND HISTORIC FEATURES BASED ON INFORMATION PROVIDED BY URS CORPORATION, USGS, AND PAL.
 - EXTENT OF UNDERGROUND WORKINGS BASED ON HISTORIC INFORMATION AND ASSUMPTIONS.
 - REFER TO FIGURE 4-2 FOR PLAN VIEW AND LOCATION OF ALIGNMENT.

LEGEND	
---	EXISTING GROUND SURFACE
---	INFERRED OVERBURDEN GROUNDWATER LEVEL
---	INFERRED BEDROCK GROUNDWATER LEVEL
---	INFERRED BEDROCK SURFACE
---	EXTENTS OF UNDERGROUND WORKINGS
	FLOTATION TAILINGS
	APPROXIMATE LOCATION OF UNDERGROUND WORKINGS
	WASTE ROCK PILE
	WASTE MATERIAL
	MAGNETIC SEPARATION WASTE MATERIAL
	UNMINED BEDROCK AREA
	OVERBURDEN (NATIVE SOIL)

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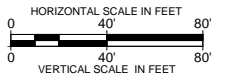
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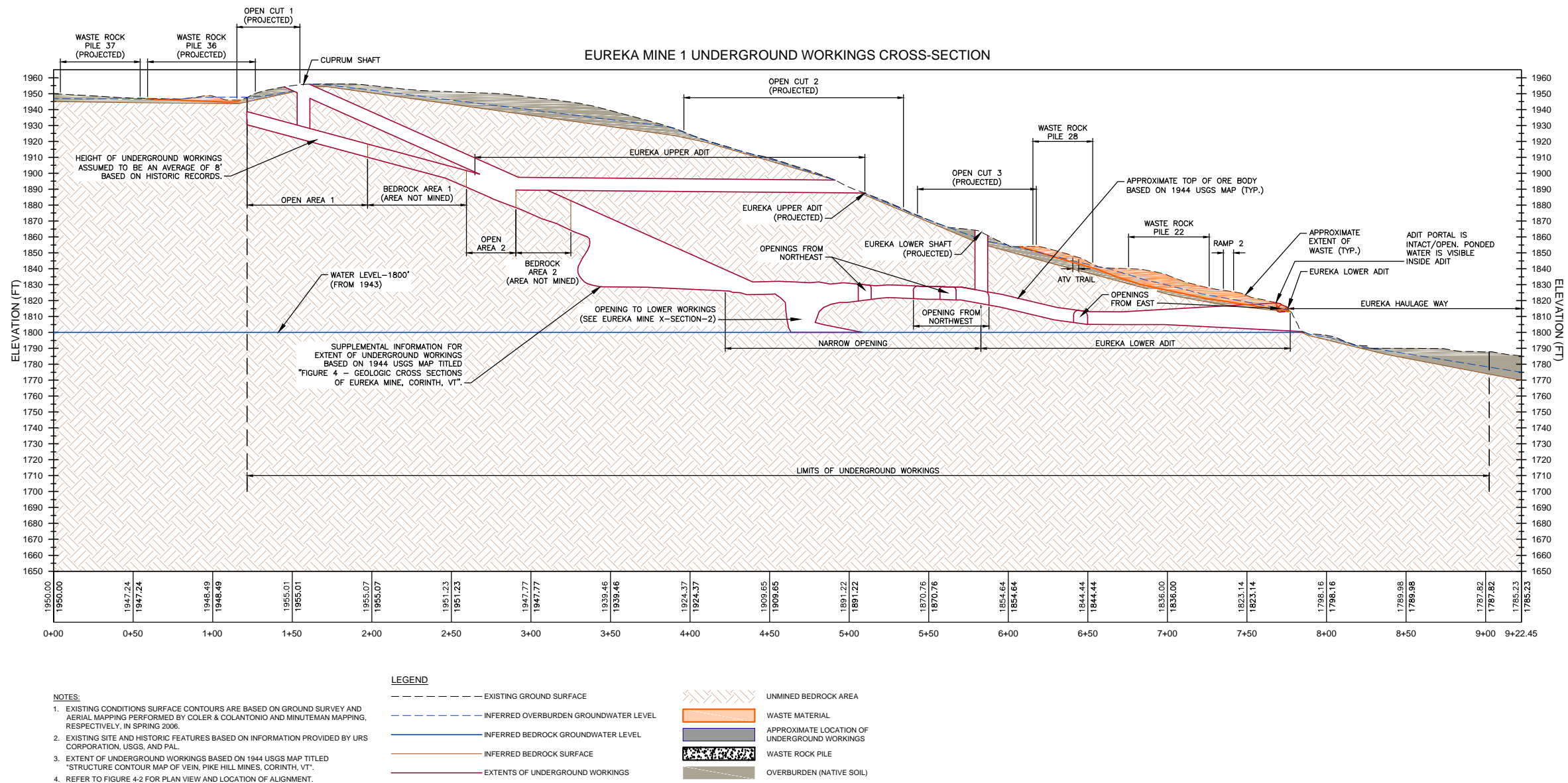
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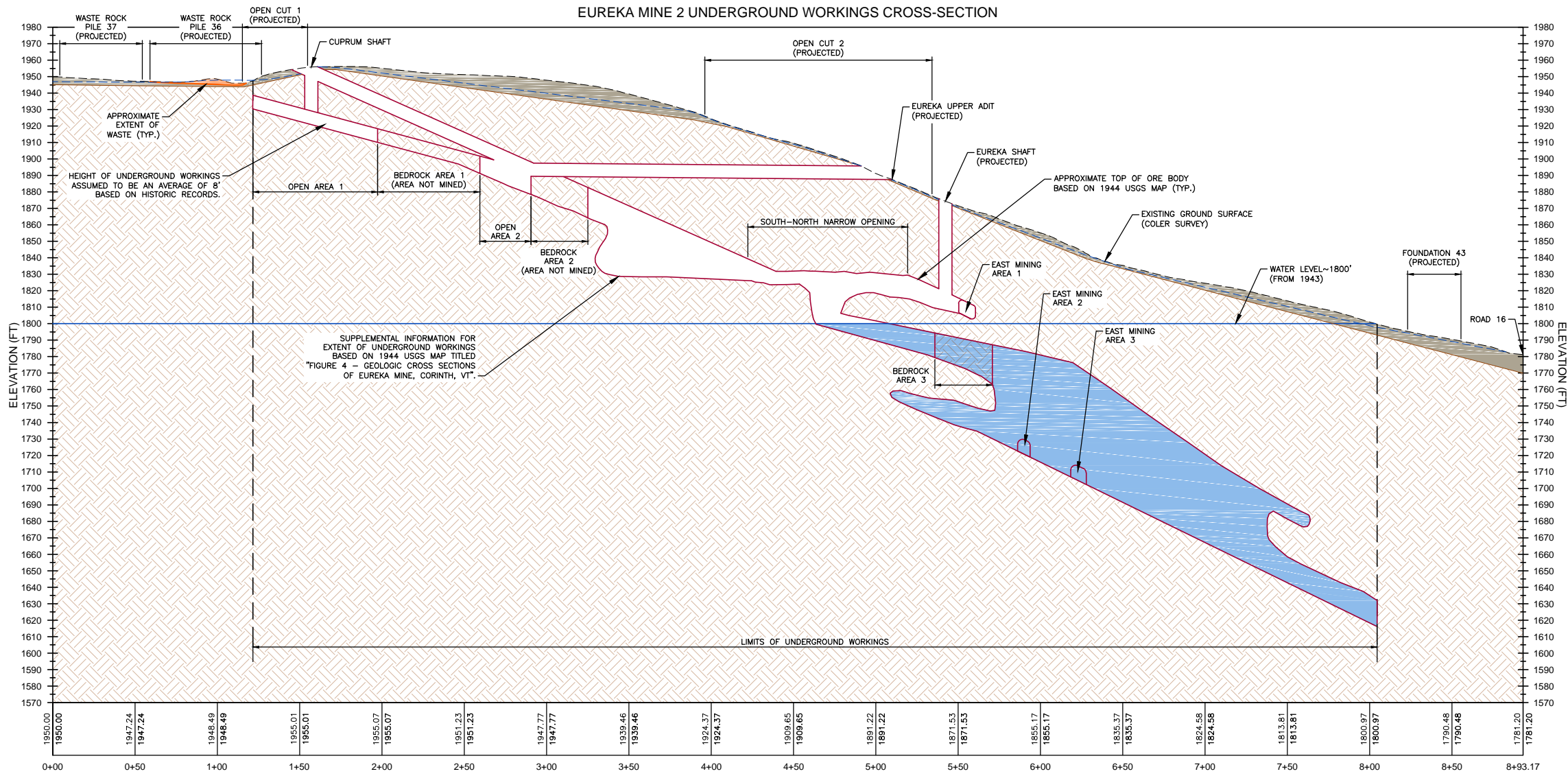
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CROSS-SECTION E-E'
EUREKA MINE 1
UNDERGROUND
WORKINGS

FIGURE
4-6A



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NOTES:

1. EXISTING CONDITIONS SURFACE CONTOURS ARE BASED ON GROUND SURVEY AND AERIAL MAPPING PERFORMED BY COLER & COLANTONIO AND MINUTEMAN MAPPING, RESPECTIVELY, IN SPRING 2006.
2. EXISTING SITE AND HISTORIC FEATURES BASED ON INFORMATION PROVIDED BY URS CORPORATION, USGS, AND PAL.
3. EXTENT OF UNDERGROUND WORKINGS BASED ON 1944 USGS MAP TITLED "STRUCTURE CONTOUR MAP OF VEIN, PIKE HILL MINES, CORINTH, VT".
4. REFER TO FIGURE 4-2 FOR PLAN VIEW AND LOCATION OF ALIGNMENT.

LEGEND

- | | | | |
|-------|---------------------------------------|--|--|
| --- | EXISTING GROUND SURFACE | | FLOODED UNDERGROUND WORKINGS |
| - - - | INFERRED OVERBURDEN GROUNDWATER LEVEL | | UNMINED BEDROCK AREA |
| --- | INFERRED BEDROCK GROUNDWATER LEVEL | | WASTE MATERIAL |
| --- | INFERRED BEDROCK SURFACE | | APPROXIMATE LOCATION OF UNDERGROUND WORKINGS |
| --- | EXTENTS OF UNDERGROUND WORKINGS | | WASTE ROCK PILE |
| --- | | | OVERBURDEN (NATIVE SOIL) |



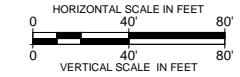
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CROSS-SECTION F-F'
EUREKA MINE 2
UNDERGROUND
WORKINGS

FIGURE
4-6B

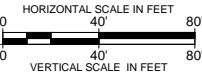
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CROSS-SECTION G-G'
SMITH MINE

FIGURE
4-7

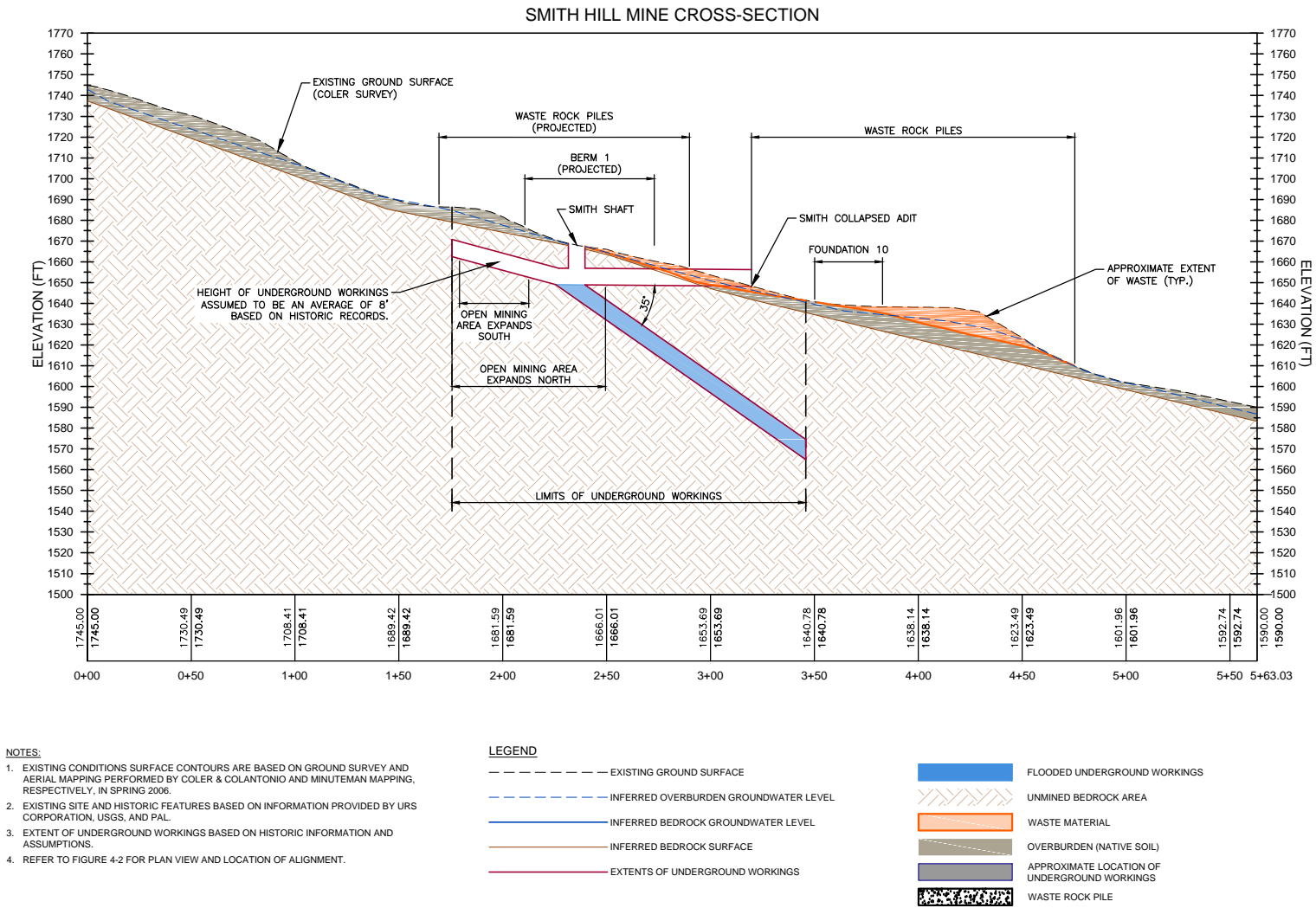
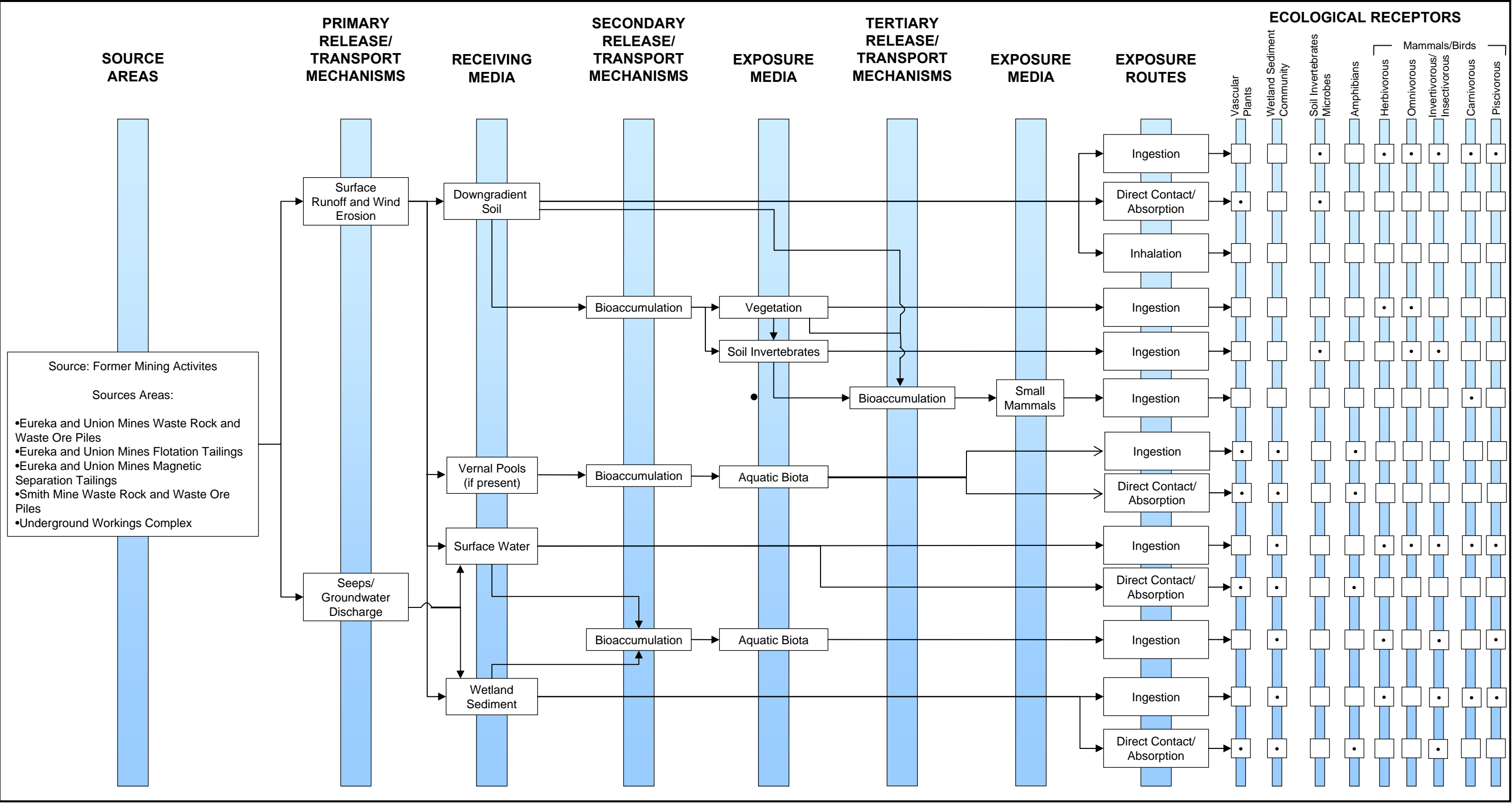
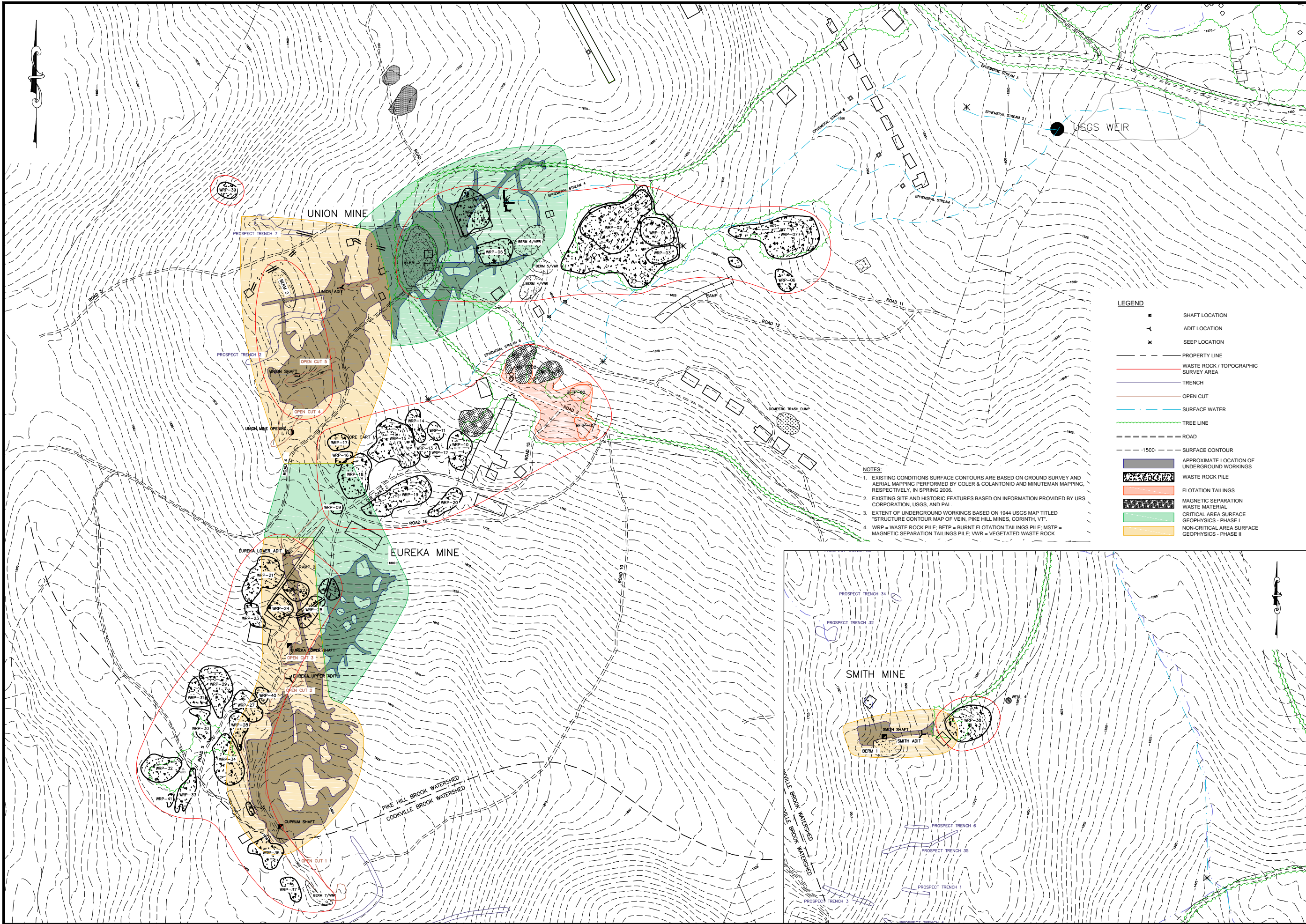


Figure 5-1
Ecological Exposure Pathway Analysis



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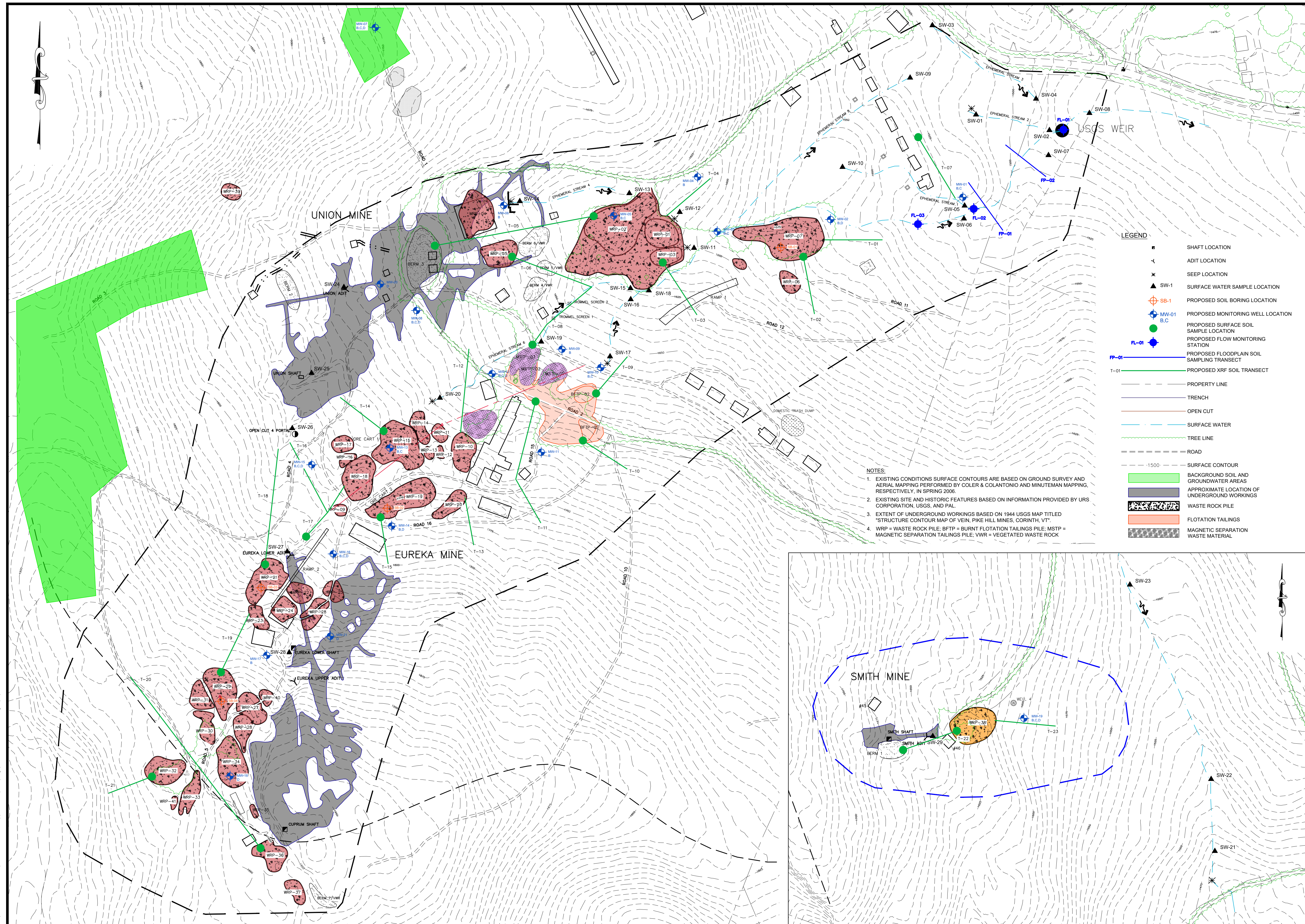
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SITE SURVEY
REQUIREMENTS

FIGURE
9-1




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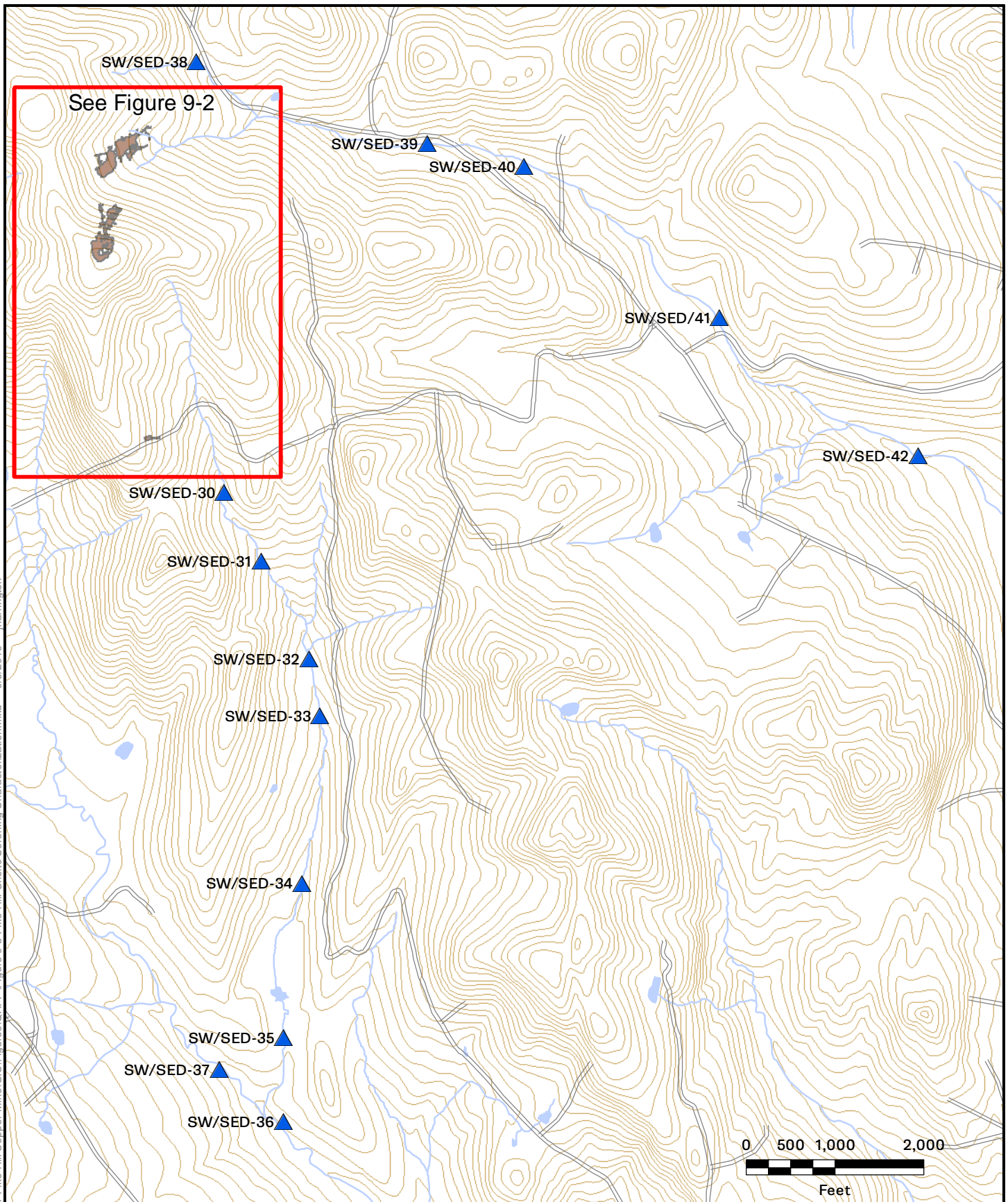
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NOBIS PROJECT NO.		80111.01
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PROPOSED ON-SITE
SCREENING AND
CHARACTERIZATION
LOCATIONS

FIGURE
9-2

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Legend



-  Proposed Surface Water/
Sediment Location
-  Underground Workings



FIGURE 9-3

PROPOSED OFF-SITE SCREENING
AND CHARACTERIZATION LOCATIONS
PIKE HILL MINE
CORINTH, VERMONT

PREPARED BY: JH
PROJECT NO. 80111

CHECKED BY: AB
DATE: SEPTEMBER 2019

TABLES

Table 3-1
Summary of USGS Mine Waste Samples
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Mine Area	Sample ID	Sample Type		Location	Parameters	Reference
Smith	04Smith1	WR piles	composite	Upper WR pile at mine	Mineralogy (X-ray diffraction), bulk chemistry for major and trace elements (ICP-AES and -MS), acid-base accounting (AP, NP, and NNP, paste pH), modified field-leach test (major, trace elements and anions via ICP-AES, -MS and ion chromatography, test kits for dissolved total iron and ferrous iron)	Piatak et al. (USGS), 2006
Smith	04Smith1-1	rock	grab	Upper WR pile at mine		
Smith	04Smith1-2	mineral	grab	Upper WR pile at mine		
Smith	04Smith2	WR piles	composite	Middle WR pile near Smith Shaft		
Smith	04Smith3	WR piles	composite	Lower WR pile near Smith Adit		
Smith	04Smith4	Hardpan	grab	Downslope of lower WR pile		
Smith	04Smith5	Soil	composite	Downslope of lower WR pile		
Smith	04Smith6	Soil	grab	Background soil near headwaters of CKBK tributary		
Smith	04Smith7	Soil	grab	Background soil near headwaters of CKBK tributary		
Eureka	04PKHL1	WR piles	composite	WR piles at top of Pike Hill		
Eureka	04PKHL2	WR Piles	composite	WR piles at top of Pike Hill		
Eureka	04PKHL2-1	rock	grab	WR piles at top of Pike Hill		
Eureka	04PKHL3	WR Piles	composite	WR piles above Eureka Lower Adit		
Eureka	04PKHL3-1	mineral	grab	WR piles above Eureka Lower Adit		
Eureka	04PKHL4-A	mineral	grab	Eureka Lower Adit		
Eureka	04PKHL4-B	mineral	grab	Eureka Lower Adit		
Eureka	04PKHL4-C	mineral	grab	Eureka Lower Adit		
Eureka	04PKHL4-D	mineral	grab	Eureka Lower Adit		
Eureka	04PKHL4-E	mineral	grab	Eureka Lower Adit		
Eureka	04PKHL4-F	mineral	grab	Eureka Lower Adit		
Union	04PKHL5-A	mineral	grab	Open Cut 4 Portal		
Union	04PKHL5-B	mineral	grab	Open Cut 4 Portal		
Union	04PKHL5-C	mineral	grab	Open Cut 4 Portal		
Union	04PKHL6	mineral	grab	Union Adit		
Eureka/Union	04PKHL7	WR Piles	composite	WR piles north-northwest of Eureka Mine		
Eureka	04PKHL8	mineral	grab	Eureka Lower Shaft		
Eureka/Union	04PKHL9	WR Piles	composite	Burned flotation tailings pile above road		
Eureka/Union	04PKHL9-A	Tailings	grab	Burned flotation tailings pile above road		
Eureka/Union	04PKHL9-B	Tailings	grab	Burned flotation tailings pile above road		
Eureka/Union	04PKHL9-C	Tailings	grab	Burned flotation tailings pile above road		
Eureka/Union	04PKHL10	Tailings	composite	Magnetic separation tailing piles		
Eureka/Union	04PKHL11	WR Piles	composite	Lower Union/Eureka WR Piles		
Eureka/Union	05PKHL11-Dup	WR Piles	composite	Lower Union/Eureka WR Piles		
Eureka/Union	04PKHL11-A	Tailings	grab	Lower Union/Eureka WR Piles		
Eureka/Union	04PKHL11-1	rock	grab	Lower Union/Eureka WR Piles		
Eureka/Union	04PKHL12	Ferricrete	grab	Seep below lower Union/Eureka WR piles		
Eureka/Union	04PKHL13	WR piles	composite	Lowermost Union/Eureka WR piles		
Eureka/Union	04PKHL13-A	rock	grab	Lowermost Union/Eureka WR piles		
Eureka/Union	04PKHL13-B	Ferricrete	grab	Lowermost Union/Eureka WR piles		
Eureka/Union	04PKHL14	mineral	grab	Lower Union/Eureka WR piles		

Notes:

WR = waste rock; CKBK = Cookville Brook

Table 3-2
Summary of USGS Surface Water, Seep, and Mine Pool Samples
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

USGS 2007 Station ID	USGS Sample ID	Corresponding Sediment Sample ID	Location	Aqueous Parameters	Reference
0	PKHL-9	NA	Tributary to PHB at lower Eureka/Union waste pile	Dissolved and total acid soluble cations, anions and alkalinity, dissolved organic carbon, pH, temperature, specific conductance, DO, ORP, dissolved ferrous iron, dissolved total iron.	USGS, 2006
1*	PKHL-10	01139830-SD	Tributary to PHB at weir, 800 ft downstream of Site 0		
2	PKHL-11	011398302-SD	Background, tributary to PHB upstream of Site at Richardson Road		
2A	PKHL-16	NA	PHB at Richardson Road, 0.5 miles downstream from Site 1		
3	01139832	01139832-SD	PHB at Carpenter Place, 0.7 miles downstream of Site 1		
4*	PKHL-12	01139833-SD	PHB at Pike Hill Road, above wetlands, 1.1 miles downstream from Site 1		
4A	01139834	NA	PHB below Pike Hill Road, above wetlands, 1.6 miles from Site 1		
5*	PKHL-13	01139838-SD	Between PHB wetlands, 3 miles downstream of Site 1		
5A	PKHL-17	NA	Background, tributary to PHB at wetlands, 900 feet upstream from Site 5		
6	PKHL-14	01139839-SD	PHB in wetlands at Miller Road, 3.8 miles downstream of Site 1		
7	01139840	01139840-SD	PHB at mouth		
8	PKHL-15	01139826-SD	Waits River 1.8 miles upstream from confluence with Pike Hill Brook		
9	01139841	01139841-SD	Waits River 0.8 miles downstream of confluence with PHB, at Village Road		
10	CKBK-1	01139940-SD	Tributary to Cookville Brook below Smith mine		
NA	CKBK-2	NA	Seep entering tributary to Cookville Brook. Aluminum precipitate near Smith mine		
NA	CKBK-3	NA	Background, upstream of Smith mine road at headwaters of unnamed tributary to Cookville Brook		
NA	CKBK-4	NA	Smith Mine stagnant pooled water north of Smith Shaft		
NA	CKBK-5	NA	Smith Shaft mine pool water		
NA	PKHL-1	NA	Eureka Lower Adit mine pool		
NA	PKHL-2	NA	Tributary to PHB downstream of Eureka/Union lowermost waste pile		
NA	PKHL-4	NA	Open Cut 4 Portal, perched		
NA	PKHL-5	NA	Union Adit mine pool		
NA	PKHL-6	NA	Stream draining Union Adit just before infiltrating lower waste piles		
NA	PKHL-7	NA	Northwestern-most seep at base of lower Eureka/Union waste dump		
NA	PKHL-8	NA	Seep at base of lower Eureka/Union waste dump above surface flow		

Notes:

*Continuous monitoring of streamflow, specific conductance, pH, and water temp., with monthly water quality samples 10/2004-09/2006

Four synoptic samples were collected from locations 1 to 9 (11/2004, 04/2005, 06/2005, 12/2005); 3 samples from location 10 (11/2004, 06/2005, 08/2005)

Additional samples were collected at locations 1 and 5 during rain and snowmelt events.

Water samples were collected at locations 1 and 5 11/2004-12/2005; Location 4 06/2005-12/2005

NA = Not applicable

PHB = Pike Hill Brook

Table 3-3
Summary of USGS Sediment Samples
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Sample ID	Corresponding Water Loc ID	Location	Parameters	Reference
01139940-SD	10, CKBK-1	Tributary to Cookville Brook below Smith mine	Composite samples analyzed for Mineralogy (XRD), bulk chemical analysis for major and trace elements by ICP-AES and-MS, Se by HG-AAS.	USGS-2006
01139830-SD	1, PKHL-10	Trib to PHB at weir, 800 ft downstream of site 0		
01139830-SD-BC	none	PHB downstream of Loc 1 below confluence with first clean tributary		
011398302-SD	2, PKHL-11	Background, trib to PHB upstream of site		
01139833-SD	4, PKHL-12	PHB at Pike Hill Road, above PHB wetlands 1.1 miles downstream from site 1		
01139838-SD	5, PKHL-13	Between PHB wetlands 3 miles downstream of site 1		
01139839-SD	6, PKHL-14	PHB at Miller Road in wetlands 3.8 miles downstream of site 1		
01139826-SD	8, PKHL-15	Background, Waits River at Rte 25, 1.8 miles upstream from confluence with Pike Hill Brook		
01139832-SD	3, 01139832	PHB at Carpenter Place, 0.7 miles downstream of site 1		
01139840-SD	7, 01139840	PHB at mouth		
01139841-SD	9, 01139841	Waits River at Village Road, 0.8 miles downstream of confluence with Pike Hill Brook		

Notes:

PHB = Pike Hill Brook

Table 3-4
Summary of USGS Macroinvertebrate Biota Samples
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Location ID	Corresponding Water/Sediment Sample ID	Location	Parameters	Reference
1	PKHL-10, 01139830-SD	Tributary to PHB at weir, 800 ft downstream of Site 0	Benthic Macroinvertebrates: VT-DEC Method, 300-individual count taxonomic ID, and metriccs (abundance, dominance, richness, composition, functional feeding groups, diversity/evenness, and biotic indices)	USGS-2007
2	PKHL-11, 011398302-SD	Background, tributary to PHB upstream of Site at Richardson Road		
3	01139832-SD	PHB at Carpenter Place, 0.7 miles downstream of Site 1		
4	PKHL-12, 01139833-SD	PHB at Pike Hill Road, above wetlands, 1.1 miles downstream from Site 1		
4A	01139834	PHB below Pike Hill Road, above wetlands, 1.6 miles from Site 1		
5	PKHL-13, 01139838-SD	Between PHB wetlands, 3 miles downstream of Site 1		
6	PKHL-14, 01139839-SD	PHB in wetlands at Miller Road, 3.8 miles downstream of Site 1		
7	01139840-SD	PHB at mouth		
8	PKHL-15, 01139826-SD	Waits River 1.8 miles upstream from confluence with Pike Hill Brook		
9	01139841-SD	Waits River 0.8 miles downstream of confluence with PHB, at Village Road		
10	CKBK-1, 01139940-SD	Tributary to Cookville Brook below Smith mine		

Notes:

PHB = Pike Hill Brook

Table 3-5
Summary of USGS Fall 2007 Aquatic Assessment Samples
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Sample ID	Sample Type	Location	Parameters	Reference
Wetland 1-1	Soil Core	Wetland 1, central area	Wetland soil cores sampled in August 2007 and analyzed for major ions, trace elements, total carbon, AVS/SEM, total sulfur, grain size, VOCs, SVOCs, pest/PCBs.	USGS, 2013
Wetland 2-1	Soil Core	Wetland 2, central area		
Wetland 3-1	Soil Core	Wetland 3, near outlet		
Wetland 3-2	Soil Core	Wetland 3,central area		
Wetland 3-3	Soil Core	Wetland 3, near channel upstream of 3-2		
Wetland 3-4	Soil Core	Wetland 3, southern margin		
Wetland 3-5	Soil Core	Wetland 3, northern margin		
Wetland 3-6	Soil Core	Wetland 3, western, upstream margin		
Wetland 4-1	Soil Core	Wetland 4, central area		
Wetland 4-2	Soil Core	Wetland 4, south margin		
100+ Locations in Wetlands 1 through 4	Soil Grab	Grid throughout	Wetland soil sampled in July 2007 at over 100 locations throughout Wetlands 1 through 4, analyzed by field XRF for Cu, Fe, Pb, and Zn. Samples collected from 0-0.5' and 0.5-1'	USGS, 2013
Wetland 3-1 through 3-5)	Surface/Pore Water	See locations above	In August 2007, surface water and pore water collected (pore water at depths of 1' and 2') for major ions, trace elements, specific conductance, pH, temp, ORP, DO, nutrients, DOC, and alkalinity.	
1	SW/PW/Sed/ Biota/Tox	At weir on tributary to PHB at Site	Surface Water: Nutrients, DOC, alkalinity, suspended sediment, major ions, trace elements, mercury. Pore Water: Nutrients, DOC, alkalinity, major ions, trace elements, mercury. Sediment: Total carbon, major ions, trace elements, Se, Hg, AVS/SEM, total S, grain size, centrifuged trace elements. Macroinvertebrates: Identification and enumeration. Fish: Identification, enumeration, trace elements, Hg. Toxicity: Surface and Pore Water; Sediment, 28 day amphipod survival and 10 day midge survival.	
4	SW/PW/Sed/ Biota/Tox	PHB at Pike Hill Road crossing.		
4A	SW/PW/Sed/ Biota/Tox	PHB below Pike Hill Road crossing, upstream of Wetland 4.		
4C	SW/PW/Sed/ Biota/Tox	PHB upstream of Wetland 3		
4E	SW/PW/Sed/ Biota/Tox	PHB downstream of Wetland 3		
5	SW/PW/Sed/ Biota/Tox	PHB at road crossing of Pike Hill Rd downstream of Wetland 2		
5A	SW/PW/Sed/ Biota/Tox	Reference tributary to PHB upgradient of Wetland 2		
6	SW/PW/Sed/ Biota/Tox	PHB downstream of Wetland 1		
10	SW/PW/Sed/ Biota/Tox	Tributary to CKBK		
10A	SW/PW/Sed/ Biota/Tox	Headwaters of tributary to CKBK		
10B	SW/PW/Sed/ Biota/Tox	Tributary to CKBK headwaters, downstream of 10A		
10C	SW/PW/Sed/ Biota/Tox	Tributary to CKBK in wetland before confluence		
10D	SW/PW/Sed/ Biota/Tox	CKBK upstream of site, reference		
11	SW/PW/Sed/ Biota/Tox	Tributary to CKBK between 10 and 10B		
12	SW/PW/Sed/ Biota/Tox	Tributary to CKBK between10 and 11		

Notes:

PHB = Pike Hill Brook, CKBK = Cookville Brook

Table 4-1
Estimated Volumes of Waste Rock and Tailings
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Mine Area	Description	Volume (cubic yards)
Eureka	Waste Rock Pile 9	30
	Waste Rock Pile 10	640
	Waste Rock Pile 11	130
	Waste Rock Pile 12	30
	Waste Rock Pile 13	10
	Waste Rock Pile 14	120
	Waste Rock Pile 15	3,270
	Waste Rock Pile 16	100
	Waste Rock Pile 17	110
	Waste Rock Pile 18	2,200
	Waste Rock Pile 19	2,000
	Waste Rock Pile 20	300
	Waste Rock Pile 21	1,500
	Waste Rock Pile 22	530
	Waste Rock Pile 23	440
	Waste Rock Pile 24	720
	Waste Rock Pile 25	120
	Waste Rock Pile 27	210
	Waste Rock Pile 28 (lower)	190
	Waste Rock Pile 28 (upper)	510
	Waste Rock Pile 29	1,090
	Waste Rock Pile 30	470
	Waste Rock Pile 31	210
	Waste Rock Pile 32	1,310
	Waste Rock Pile 33	310
	Waste Rock Pile 34	410
	Waste Rock Pile 35	5
	Waste Rock Pile 36	510
	Waste Rock Pile 37	50
	Waste Rock Pile 40	10
	Waste Rock Pile 41	30
	Berm 7 / Vegetated Waste Rock	40
	Burnt Flotation Tailings Pile 1	60
	Burnt Flotation Tailings Pile 2	40
	Flotation Tailings	780
	Magnetic Separation Tailings Pile 1	340
	Magnetic Separation Tailings Pile 2 & 3	310
	Magnetic Separation Waste Material	140
	Total volume:	19,275

Table 4-1
Estimated Volumes of Waste Rock and Tailings
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Mine Area	Description	Volume (cubic yards)
Union	Waste Rock Pile 1	1,030
	Waste Rock Pile 2	3,130
	Waste Rock Pile 3	350
	Waste Rock Pile 4	1,780
	Waste Rock Pile 5	1,110
	Waste Rock Pile 6	220
	Waste Rock Pile 7	3,900
	Waste Rock Pile 39	100
	Berm 2	130
	Berm 3	2,090
	Berm 4 / Vegetated Waste Rock	340
	Berm 5 / Vegetated Waste Rock	90
	Berm 6 / Vegetated Waste Rock	170
	Unnamed Waste Rock Pile 1	0
	Unnamed Waste Rock Pile 2	990
	Total volume:	15,430
Smith	Waste Rock Pile 38	1,170
	Berm 1	530
	Total volume:	1,700
Total Waste Volume (all three areas)		36,405

Notes:

1. Waste volumes generated using AutoCAD Civil 3D 2015.
2. Waste volumes are neat (in-place) volumes.
3. Waste volumes do not include any contingency.
4. Bottom of waste surface (inferred contours) generated by Nobis based on assumed undisturbed adjacent surface contours (existing ground)
5. Waste volumes based on comparison of inferred bottom of waste contours versus existing ground surface from Coler Survey.

Table 5-1
Human Health Risk Assessment Exposure Areas
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Proposed Exposure Area	Description of Proposed Exposure Area (see Appendix B of PAL, 2011)
SOIL	
Union Mine Waste Piles	Waste Rock Piles 1 through 7 and 39; Berms 2 through 6 and 8
Eureka Mine Tailings Piles	Magnetic Separation Waste Material Pile; Magnetic Separation Tailings Piles 1, 2, 3; Burnt Flotation Tailings Piles 1 and 2
Eureka Mine Waste Piles	Waste Rock Piles 9 through 37 and 40; Berm 7
Smith Mine	Waste Rock Pile 38; Berm 1
Surface Water and Sediment	
Pike Hill Brook Downstream to Wetlands Complex	3.5 km reach of Pike Hill Brook.
Pike Hill Brook Wetlands Complex	Approximately 70-acre wetland area
Pike Hill Brook Wetlands Complex Downstream to Waits River	3 km reach of Pike Hill Brook.
Unnamed Tributary to Cookville Brook	1.6 km reach.
South Branch of Waits River (Cookville Brook and tributaries)	8 km reach.
Fish	
Areas where edible fish or surrogates have been collected (i.e., Pike Hill Brook, tributary to Cookville Brook, and a reference area).	
Groundwater	
Eureka and Union Mines	Monitoring wells associated with the Eureka and Union Mines.
Smith Mine	Monitoring wells associated with the Smith Mine.
Off-Site	Monitoring wells located off-site.

Table 5-2
Recreational Visitor Exposure Parameters
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

		Adolescent Recreational Visitor		Adult Recreational Visitor	
		All Pathways			
Receptor Age		10-18 years		Adult	
ED (years)		8	Estimated	20	(1)
BW (kg)		57	(2)	80	EPA, 2014
AT-Cancer (days)		25550	EPA, 1989	25550	EPA, 1989
AT-Noncancer (days)		2920	Calculated	7300	Calculated
		Soil Exposure Specific			
ABS (unitless)		COPC specific (EPA, 2004)			
EF _{soil} (days/year)		104	(3)	104	(3)
IRS (mg/day)		100	EPA, 2014	100	EPA, 2014
FI		1		1	
SA _{soil} (cm ² /day)		5230	(4)	6032	EPA, 2014
AF (mg/cm ²)		0.2	(5)	0.2	(5)
PEF (m ³ /kg)		Calculated	(6)	Calculated	(6)
		Mine Pool Water Exposure Specific			
EF _{mine pool water} (days/year)		5	(7)	5	(7)
IRW _{inc} (L/hr)		0.05	EPA, 1989	0.05	EPA, 1989
ET (hrs/day)		1	Estimated	1	Estimated
Kp (cm/hr)		COPC specific (EPA, 2004)			
SA _{mine pool water} (cm ² /day)		2318	(8)	3470	(8)

Notes:

- (1) Adult visitor is assumed to be a local resident.
- (2) Average body weight for males and females ages 10 to 18, see Table 8-14 NHANES 1999-2002 of EPA. 2011.
- (3) Exposure is assumed to occur 3 times a week from April through November (8 months) (4.33 weeks/month). The visitors are not assumed to visit the site during December, January, February, and March.
- (4) Assumes that the head, hands, forearms, lower legs and feet are exposed. Adolescent SA calculated using data from U.S. EPA 2011, Tables 7-1 and 7-8. Adult SA calculated using data from U.S. EPA 2011, Tables 7-2 and 7-12.
- (5) Geometric mean for heavy equipment operators, EPA, 2004.
- (6) PEF will be based on truck traffic on unpaved roads.
- (7) Exposure is assumed to occur once a month from May through September.
- (8) Assumes that the head, hands, and forearms are exposed. Calculated using data from U.S. EPA 2011, Tables 7-1, 7-2, and 7-8.

Definitions

ABS = dermal absorption factor
 AF = soil-to-skin adherence factor
 AT-Cancer = carcinogenic averaging time
 AT-Noncancer = noncancer averaging time
 BW = body weight
 ED = exposure duration
 EF = exposure frequency

ET = exposure time
 FI = fraction ingested
 IRS = incidental soil ingestion rate
 IRW_{inc} = incidental surface water ingestion rate
 Kp = dermal permeability coefficient
 PEF = particulate emission factor
 SA = exposed skin surface area

Table 5-3
Swimmer/Wader Exposure Parameters
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

	Adolescent Swimmer/Wader		Adult Swimmer/Wader		
	All Pathways				
	Receptor Age	10-18 years		Adult	
	ED (years)	8	Estimated	20	(1)
	EF (days/year)	22	(2)	22	(2)
	BW (kg)	57	(3)	80	EPA, 2014
	AT-Cancer (days)	25550	EPA, 1989	25550	EPA, 1989
	AT-Noncancer (days)	2920	Calculated	7300	Calculated
	Sediment Exposure Specific				
	ABS (unitless)	COPC specific (EPA, 2004)			
IRSED (mg/day)	100	EPA, 2014	100	EPA, 2014	
FI	1		1		
SA _{sediment} (cm ² /day)	5230	(4)	6032	EPA, 2014	
AF (mg/cm ²)	0.32	(5)	0.32	(5)	
Surface Water Exposure Specific					
IRW _{inc} (L/hr)	0.05	EPA, 1989	0.05	EPA, 1989	
ET (hrs/day)	2	Estimated	2	Estimated	
Kp (cm/hr)	COPC specific (EPA, 2004)				
SA _{surface water} (cm ² /day)	15900	(6)	20900	EPA, 2014	

Notes:

- (1) Adult visitor is assumed to be a local resident.
- (2) Exposure is assumed to occur once a week from May through September (4.33 weeks/month).
- (3) Average body weight for males and females ages 10 to 18, see Table 8-14 NHANES 1999-2002 of EPA, 2011.
- (4) Assumes that the head, hands, forearms, lower legs and feet are exposed. Calculated using data from U.S. EPA 2011, Tables 7-1 and 7-8.
- (5) Geometric mean for reed gatherers, EPA, 2004.
- (6) Assumes body is fully immersed while swimming. U.S. EPA 2011, Table 7.1; weighted average of mean values for 11-16 yr old.

Definitions

ABS = dermal absorption factor	ET = exposure time
AF = soil-to-skin adherence factor	FI = fraction ingested
AT-Cancer = carcinogenic averaging time	IRSED = incidental sediment ingestion rate
AT-Noncancer = noncancer averaging time	IRW _{inc} = incidental surface water ingestion rate
BW = body weight	Kp = dermal permeability coefficient
ED = exposure duration	SA = exposed skin surface area
EF = exposure frequency	

Table 5-4
Fish Consumer Exposure Parameters
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

	Young Child Fisherman		Adult Fisherman	
Receptor Age	1-6 years		Adult	
IRF (kg/day)	TBD		TBD	
EF (days/year)	350		350	
ED (years)	6	Estimated	20	EPA, 2014
BW (kg)	15	EPA, 2014	80	EPA, 2014
AT-Cancer (days)	25550	EPA, 1989	25550	EPA, 1989
AT-Noncancer (days)	2190	Calculated	7300	Calculated

Definitions

AT-Cancer = carcinogenic averaging time
AT-Noncancer = noncancer averaging time
BW = body weight
ED = exposure duration
EF = exposure frequency
IRF = fish ingestion rate

Table 5-5
Resident Exposure Parameters
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

		Child Resident		Adult Resident	
		All Pathways			
Receptor Age		1-6 years		Adult	
ED (years)		6	EPA, 2014	20	EPA, 2014
BW (kg)		15	EPA, 2014	80	EPA, 2014
AT-Cancer (days)		25550	EPA, 1989	25550	EPA, 1989
AT-Noncancer (days)		2190	Calculated	7300	Calculated
		Soil Exposure Specific			
IRS (mg/day)		200	EPA, 2014	100	EPA, 2014
EF _{soil} (days/year)		350	EPA, 2014	350	EPA, 2014
FI		1		1	
ABS (unitless)		COPC specific (EPA, 2004)			
SA (cm ² /day)		2690	EPA, 2014	6032	EPA, 2014
AF (mg/cm ²)		0.2	EPA, 2014	0.07	EPA, 2014
PEF (m ³ /kg)		Calculated (1)		Calculated (1)	
		Groundwater Exposure Specific			
EF _{groundwater} (days/year)		350	EPA, 2014	350	EPA, 2014
IRW (L/day)		0.78	EPA, 2014	2.5	EPA, 2014
Kp (cm/hr)		COPC specific (EPA, 2004)			
SA _{bathing/showering} (cm ² /day)		6378	EPA, 2014	20900	EPA, 2014
T _{event} (hrs/event)		0.54	EPA, 2014	0.71	EPA, 2014

Notes:

(1) PEF will be based on wind erosion using regional-specific data.

Definitions

ABS = dermal absorption factor

AF = soil-to-skin adherence factor

AT-Cancer = carcinogenic averaging time

AT-Noncancer = noncancer averaging time

BW = body weight

ED = exposure duration

EF = exposure frequency

FI = fraction ingested

IRS = incidental soil ingestion rate

IRW = water ingestion rate

Kp = dermal permeability coefficient

PEF = particulate emission factor

SA = exposed skin surface area

Table 5-6
Construction Worker Exposure Parameters
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

	Construction Worker	
Receptor Age	Adult	
IRS (mg/day)	330	EPA, 2017
FI	1	
EF (days/year)	60	(1)
ED (years)	1	(2)
ABS (unitless)	COPC specific (EPA, 2004)	
SA (cm²/day)	3470	EPA, 2014
AF (mg/cm²)	0.2	(3)
BW (kg)	80	EPA, 2014
PEF (m³/kg)	Calculated	(4)
AT-Cancer (days)	25550	EPA, 1989
AT-Noncancer (days)	365	Calculated

Notes:

- (1) Assumes the construction worker is exposed 5 days per week for a total of 12 weeks.
- (2) Assumes the construction is exposed for 1 year.
- (3) Geometric mean for heavy equipment operators, EPA, 2004.
- (4) PEF will be based on truck traffic on unpaved roads.

Definitions

ABS = dermal absorption factor
 AF = soil-to-skin adherence factor
 AT-Cancer = carcinogenic averaging time
 AT-Noncancer = noncancer averaging time
 BW = body weight
 ED = exposure duration

EF = exposure frequency
 FI = fraction ingested
 IRS = incidental soil ingestion rate
 PEF = particulate emission factor
 SA = exposed skin surface area

2017 = RSLs
 2014 = default assump
 2011 = expos factor handbook
 2004 = derm guid

Table 5-7
Terrestrial Receptors, Environmental Communities, and Exposure Areas
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Receptor/Community	Exposure Area
Vascular plants	Terrestrial habitats (Eureka/Union and Smith Mines)
Soil invertebrate/microbes	Terrestrial habitats (Eureka/Union and Smith Mines)
Herbivorous birds/mammals Song sparrow Meadow vole	Terrestrial habitats (Eureka/Union and Smith Mines) Surface waters
Omnivorous birds/mammals Red-winged blackbird White-footed mouse	Terrestrial habitats (Eureka/Union and Smith Mines) Surface waters
Invertivorous birds/mammals American robin Short-tailed shrew	Terrestrial habitats (Eureka/Union and Smith Mines) Surface waters
Carnivorous birds/mammals American kestrel Mink	Terrestrial habitats (Eureka/Union and Smith Mines) Surface waters

Table 6-1
Preliminary Chemical-Specific ARARs
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Requirement	STATUS
STATE ARARs	
Vermont Water Quality Standards, VT Env. Prot. R. Chapter 29(a), Ch. 1, 2, and 3 and Appendix C and D	Applicable
Groundwater Protection, 10 V.S.A. Ch 48, Groundwater Rule and Strategy, VT Env. Prot. R. Ch. 12, Appendix One, Table 1 Primary Groundwater Protection Standards	Applicable
FEDERAL ARARs	
Federal Clean Water Act (CWA), Federal Ambient Water Quality Criteria, 40 CFR Part 122.44	Applicable
EPA National Recommended Water Quality Criteria – EPA 822-R-02-047, EPA 2002.	To Be Considered
Proposed Guidelines for the Clean-Up of Contaminated Sites in Ontario (Ministry of Environment and Energy of Ontario [MOE], 1994)	To Be Considered
EPA Residential Risk Based Concentrations (RBCs) (Region III) and Preliminary Remediation Goal (PRGs) (Region IX) – Residential	To Be Considered
EPA Risk Reference Doses (RfDs)	To Be Considered
EPA Carcinogen Assessment Group, Cancer Slope Factors (CSFs)	To Be Considered
Guidelines for Carcinogen Risk Assessment EPA/630/P-03/001F (March 2005)	To Be Considered
Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens EPA/630/R-03/003F (March 2005)	To Be Considered
<i>Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems</i> (MacDonald et al., 2000)	To Be Considered
<i>Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments</i> (Long et al. 1995)	To Be Considered
<i>Preliminary Remediation Goals for Ecological Endpoints</i> , Efroymsen et al., August 1997	To Be Considered
<i>Memorandum: OSWER Directive: Clarification to the 1994 Revised Interim Soil Lead (Pb) Guidance for CERCLA Sites and RCRA Corrective Action Facilities</i> , EPA/540/F-98-030, August 1998	To Be Considered

Table 6-2
Preliminary Location-Specific ARARs
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Requirement	Status
STATE ARARs	
Vermont Wetlands Act, 10 VSA § 905; Vermont Wetland Rules (Nat. Res. Brd., Water Res. P. 12-004-056)	Applicable
Vermont's Land Use and Development Law (Act 250), 10 VSA Chapter 151	Applicable
Vermont Regulation of Stream Flow, 10 VSA Chapter 41	Applicable
Vermont Obstruction of Streams, 10 VSA Chapter 111, § 1407	Applicable
Vermont Historic Preservation Law, 22 VSA §§ 743(4), 761, 763, and 767.	Relevant and Appropriate
Vermont Endangered Species Law, 10 VSA, Chapter 123, § 5402(a).	Applicable
Vermont ANR Guidance on Riparian Buffers (December 5, 2005)	To be Considered
FEDERAL ARARs	
Federal Protection of Wetlands, Executive Order 11990, 40 CFR 6, App. A	Applicable
Federal Clean Water Act, Section 404, 33 USC § 1344; 40 CFR Part 230; 33 CFR Parts 320-323	Applicable
Federal Floodplain Management, Executive Order 11988, 40 CFR 6, App. A	Applicable
Floodplain Management and Protection of Wetlands, 44 C.F.R. 9	Relevant and Appropriate
Federal Fish and Wildlife Coordination Act; 16 USC 661 <i>et seq.</i> , as amended; 40 CFR 6.302	Applicable
Federal Endangered Species Act of 1973 (ESA), 16 USC 1531 <i>et seq.</i> ; 33 CFR Part 320	To Be Considered
National Historic Preservation Act (NHPA), Section 106, 16 USC 470 <i>et seq.</i> , 36 CFR Part 800	Applicable
Archeological and Historic Preservation Act, 16 USC 469 <i>et seq.</i> , 36 CFR, Part 65	Applicable

Table 6-3
Preliminary Action-Specific ARARs
Pike Hill Copper Mine Superfund Site
Corinth, Vermont

Requirement	Status
STATE ARARs	
Vermont Water Quality Standards, VT Env. Prot. R. Ch. 29(A), Ch. 1, 2, and 3 and Appendix C and D (October 2014)	Applicable
Vermont Groundwater Protection Act (10 VSA §§ 1390-94) and Vermont Groundwater Protection Rule and Strategy, Env. Prot. R. Ch. 12-702 and 703	Applicable
Vermont Water Pollution Control Act, 10 VSA Chapter 47; Vermont Water Quality Standards, Ch. 1, 2, and 3 and Appendix C and D	Applicable
Vermont National Pollutant Discharge Elimination System (NPDES) Regulations Ch. 13 (Nat. Res. Brd., Water Res. P. 12-004-052)	Applicable
Vermont Department of Health Drinking Water Guidance (October 2000).	To Be Considered
Vermont Solid Waste Management Rules (VSWMR), Management of Mining and Mineral Processing Waste, Env. Prot. R. Ch. 6, Subchapter 13	Applicable
Vermont Stormwater Management Act, 10 VSA § 1263 and §1264; Vermont Stormwater Management Rule, Env. Prot. R.Ch. 18	Applicable
Vermont Air Pollution Control Act, 10 VSA Chapter 23 and Air Pollution Control Regulations, Env. Prot. R. Ch. 5	Applicable
Vermont Slash Removal, 10 VSA § 2648	Applicable
Vermont Waste Management Act, 10 VSA Chapter 159 and Hazardous Waste Management Regulations, Env. Prot. R. Ch. 7	Applicable
Vermont Underground Injection Control Rule (Env. Prot. R.Ch. 11)	Relevant and Appropriate
Vermont Handbook for Erosion Prevention and Sediment Control, Working Interim Document, Released in 2003 (VTDEC, 2003)	To Be Considered
FEDERAL ARARs	
Federal Safe Drinking Water Maximum Contaminant Levels (MCLs) and Maximum Contaminant Level Goals (MCLGs), National Primary Drinking Water Regulations, 40 CFR Parts 141.11 – 141.16 and 141.50 – 141.53	Relevant and Appropriate for MCLs and non-zero MCLGs only
Health Advisories (EPA Office of Drinking Water)	To Be Considered
Resource Conservation and Recovery Act, 42 USC §§ 6901-6992; 40 CFR Part 264	Relevant and Appropriate
Federal Clean Water Act, National Recommended Water Quality Criteria (NRWQC), 40 CFR Part 122.44	Relevant and Appropriate
Federal Clean Water Act, Section 402 – National Pollution Discharge Elimination System (33 USC 1342; 40 CFR 122-135, 131)	Relevant and Appropriate
Federal Clean Water Act – Groundwater Injection Standards, 40 CFR 144, 146, 147	Relevant and Appropriate
Federal Clean Water Act – Stormwater Requirements for Construction Sites; 40 CFR 122.26	Applicable
Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (EPA-540-R-05-012 OSWER 9355.0-85 December 2005)	To Be Considered
Federal Surface Mining Control and Reclamation Act of 1977, 30 USC §§ 1201-1328; 30 CFR 816 and 817	Relevant and Appropriate

Table 7-1
Screening of Potential Treatment Options for Waste Piles
Pike Hill Copper Mine Superfund Site
Corinth, Vermont
Page 1 of 4

GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
No Action	No Action	No Action	In accordance with CERCLA and NCP requirements, a No Action response must be developed to provide a baseline for comparison with other response actions. The "No Action" alternative includes only scheduled 5-Year Reviews to assess the alternative effectiveness and compliance with PRGs. It does not include any active or passive treatment of media, institutional controls, or monitoring.	Not effective for waste piles containment, reduction and/or remediation.	Implementable.	Low. Include periodic monitoring and 5-year reviews
Limited Action	Institutional Controls	Land Use Restrictions	A land use restriction is intended to prevent specific uses or activities in order to minimize potential exposure to humans and the environment. Land use restrictions may be enacted to protect against potential hazards, to preserve a remedial action, or to restrict future land uses. Land use restrictions can be implemented by altering the deed or title of record or through re-zoning. These alterations would remain in effect in perpetuity, regardless of changes in ownership of the property.	May not meet cleanup goals alone, but may be used in conjunction with other options. This process option would aid in deterring land use practices that would cause increased exposure risks to human receptors.	Implementable. Requires agreement by current land owner and possibly public acceptance.	Low capital and O&M costs.
		Informational/Educational Devices	Informational/educational devices consist of meetings or literature aimed at raising the public's knowledge of the site and addressing their concerns. Topics addressed may include the potential hazards posed by contaminants or encountered during implementation of the remedial alternative, or the purpose and effectiveness of the remedial actions.	May not meet cleanup goals for the Site alone, but may be used in conjunction with other options. Informational/educational devices would effectively inform the public about the Site.	Implementable.	Low capital and O&M costs.
	Engineered Controls	Engineered Controls	Engineered controls are physical deterrents to restrict access, reducing the potential for exposure to contaminants. Fencing installed around the perimeter(s) of the source area(s) would prohibit human and animal access. Posted warnings identify potential hazards present at the Site and discourage trespassing and misuse. Security systems and patrols also deter trespassing and misuse.	May not meet cleanup goals for the Site alone, but may be used in conjunction with other options. These items would restrict access to the Site, thereby impeding the potential for exposure to contaminants.	Implementable.	Low capital and O&M costs.
Containment	Surface Controls	Grading	Grading is the practice of reshaping the ground surface to planned contours that improve the flow of surface water, increase the stability of sloped surfaces, and/or reduce ponding and erosion.	Grading would be effective in minimizing erosion. It would not effectively satisfy the cleanup goals for the Site alone, but may be used in conjunction with other process options.	Steep slopes and shallow soils may impact implementability. The large size of some waste ore/rock materials increases difficulty and slows progress. Overall, grading is implementable.	Moderate capital and low O&M costs.
		Revegetation	Vegetation protects soil from water and wind erosion. The aboveground portions of the plants protect the soil by slowing surface water flow, thereby minimizing surface scouring and encouraging water infiltration into the soil. Plants may also filter sediment and other materials out of runoff. Root systems aid soil stabilization by holding soil particles in place.	This process option would be effective in increasing infiltration and minimizing erosion. It would not effectively achieve the cleanup goals for the Site alone, but may be used in conjunction with other process options.	Revegetation is a common practice, and materials, equipment, and skilled workers are readily available. This process option would need to occur after some type of treatment action is taken because the current material characteristics are not suitable for vegetation.	Low capital and O&M costs.
		Mulching and Erosion Control Mats	Mulches and erosion control mats are typically applied to form a temporary protective cover for soil to allow the establishment of vegetation. They provide a favorable environment for seed germination and growth in addition to reducing overland flow, water loss and precipitation impacts.	This process option would be effective in reducing run-on and erosion. It would not effectively satisfy the cleanup goals for the Site alone, but may be used in conjunction with other process options.	Materials are widely available and simple to apply.	Low capital and O&M costs.
		Retaining Walls	Retaining walls are used to improve slope stability and prevent erosion. They can also be employed to control water flow. Retaining walls can be used during or after construction activities.	This process option would be effective in increasing slope stability and minimizing erosion. It would not effectively achieve the cleanup goals for the Site alone, but may be used in conjunction with other process options.	This process option would most likely be accomplished with the use of conventional equipment and methods. Site conditions such as steep slopes and shallow soils may impact implementability.	Moderate capital and low O&M costs.
Containment	Capping Systems	RCRA Subtitle C Cap	RCRA Subtitle C caps, used for hazardous waste applications, typically consist of the following components from top to bottom: Vegetative Layer (6 inches topsoil); Protective Layer (1 to 1 ½ feet soil); Drainage Layer (1 foot sand); Primary Synthetic Barrier (40-mil geosynthetic membrane); Secondary Synthetic Barrier (geosynthetic clay liner); Gas Vent Layer (1 foot of sand or geosynthetic material); and Foundation Layer (native soil).	This type of cap would be protective of human health and the environment by eliminating direct contact with contaminants and reducing contaminant migration. However, a system that incorporates multiple low permeability layers may not be required given the characteristics of the material to be contained.	Materials, equipment, and skilled laborers are readily available. Steep slopes and shallow soils may impact implementability. The pitch of the sideslopes will ideally fall between 4 and 18 degrees in order to allow the cap to shed water and facilitate the use of conventional construction equipment. These slopes may require grading and addition of fill. Improvements to access routes may	High capital and moderate O&M costs.

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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
		Vermont Solid Waste (RCRA Subtitle D) Cap	RCRA Subtitle D caps, used for non-hazardous waste landfills, typically consist of three components (from top to bottom): Vegetative Layer (6 inches of topsoil); Earthen/Synthetic Barrier (geosynthetic clay liner); and Foundation Layer (native soil).	This type of cap would be protective of human health and the environment by eliminating direct contact with contaminants and reducing contaminant migration. Given the waste type present at the Site, a RCRA Subtitle D cap may provide adequate protection of human health and the environment.	also be required. Increased exposure risks to workers handling the material would be mitigated using proper personal protective equipment (PPE) and environmental construction protocols. Permits would be required. Institutional controls would be required to ensure the long-term protectiveness of the cap.	Moderate capital and O&M costs.
Removal and Disposal	Excavation	Excavation	Excavation refers to the removal of impacted waste piles for ex-situ treatment and/or on-site consolidation or off-site disposal.	Excavation would be effective in removing the contaminated media from the subsurface, thereby eliminating the source of surface water and groundwater impacts emanating from an area of concern.	Skilled technicians and equipment are readily available. Risks to workers and the surrounding community would be minimized using protocols to control contamination, including air monitoring, dust suppression techniques, and PPE. The large size of some of the waste ore/rock increases difficulty and slows progress. Diversion of surface water and erosion controls would be required	High capital and low O&M costs.
	Disposal	On-Site Consolidation	On-site consolidation consists of merging waste rock piles into an engineered containment cell within the remedial area.	An on-site consolidation cell would minimize the surface area upon which impacted material resides. It would be effective in preventing direct contact exposures to human and environmental receptors. The long-term effectiveness and permanence of the cell would be ensured through the implementation of land use restrictions and a groundwater monitoring program.	Materials, equipment, and skilled laborers are readily available. Steep slopes and shallow soils may influence implementability. The large size of some of the waste piles may increase difficulty and slow progress. Access routes will likely require significant improvement. Exposure risks posed to workers handling impacted material would be mitigated through the use of adequate PPE and environmental construction protocols. No impacted materials would be transported offsite for this process option. This process option would be performed in conjunction with capping, described above.	Moderate to high capital and moderate O&M costs.
		Off-Site Disposal	This process option would entail the transport of waste piles from the site to a licensed, off-site disposal facility.	Off-site disposal is applicable to the contaminants present at the Site. This process option would reduce the on-site volume of contaminants and prevent exposure to human and environmental receptors via placement of impacted materials in a licensed, off-site disposal facility.	The waste ore/rock may need to be crushed to facilitate transport and landfill acceptance. The contaminants may require stabilization prior to transport/disposal prevent leaching. Significant improvements and/or new roads may be required to facilitate construction and transport traffic. Further, there would be increased risks to workers handling the material as well as increased risks and significant disturbance to communities along the transportation route. Given these limitations and considering the on-site consolidation capacity, off-site disposal is not a practical or viable option.	High capital and no O&M costs.
In-Situ Treatment	In-Situ Biological Treatment	Enhanced Bioremediation	Enhanced bioremediation uses amendments to stimulate microorganisms, enabling them to convert contaminants into less harmful forms. Bioremediation cannot degrade inorganic contaminants, however, it can be used to change the valence state of inorganics resulting in adsorption, immobilization and accumulation of inorganics in microorganisms.	This technology has the potential to reduce the mobility, bioavailability, and toxicity of site contaminants, although high concentrations of heavy metals may be toxic to the microorganisms. The rate at which bioremediation occurs will decrease in colder temperatures.	This process option is not applicable to waste piles due to delivery and mixing issues.	Low capital and moderate O&M costs.
		Phytoremediation	Phytoremediation employs specifically selected plants to remove, store, or reduce the toxicity of contaminants. While high contaminant concentrations can be toxic to most plants, hyperaccumulator plants have the ability to handle significant amounts of inorganic contaminants. Phytoremediation is applicable to a wide range of inorganic contaminants.	The effectiveness of this technology, in general, would be driven by the ability to find plants that are compatible with the Site contaminants, contaminant concentrations, and climate. Phytoremediation would only be effective within reach of the plant roots (i.e., shallow contamination) and the majority of the contamination at the Site is deeper.	In its current state, phytoremediation is not applicable. A soil layer for vegetative support would be required. Also, for some Site areas, the steep slope faces would require leveling and/or significant erosion control measures in order to sustain vegetation. Institutional controls would be required in order to protect the plants against dangerous land uses as well as to prevent potential receptors from contacting the plants.	Moderate capital and O&M costs.
	In-Situ Physical/ Chemical Treatment	Electrokinetic Separation	Electrokinetic separation involves the application of a low voltage direct current across a pair of electrodes implanted on opposite sides of a contaminated soil mass. Contaminants are transported toward either of the electrodes via electroosmosis (water transport from anode to cathode) and electromigration (ion transport to the oppositely-charged electrode). Additives may be applied to the subsurface to augment contaminant movement. These chemicals need to be neutralized or recovered after completion. Once the contaminants are concentrated at either electrode, they are typically extracted for treatment/disposal.	Conditions in the areas of concern are not in the optimum range for treatment by electrokinetic separation, which has been demonstrated to be most effective in treating clayey soils with a moisture content between 14-18%. Additionally, there is the potential for this process to produce undesirable by-products.	A site investigation for subsurface obstructions, particularly those that are highly conductive or insulative and would disrupt this technology, should be performed. This technology is also relatively energy-intensive, which would increase overall costs.	Moderate capital and low O&M costs.

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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
		Soil Flushing	In soil flushing, a flushing solution (typically water or water containing a solvent or surfactant) is applied to subsurface soils via injection or infiltration. The flushing solution leaches and captures the contaminant. The flushing solution and contaminants are then extracted and the contaminants are separated from the flushing solution. The flushing solution can then be revitalized and reused or treated/discharged.	Soil flushing would not be effective in treating the waste piles because the metals are ingrained in the waste rock and therefore are not amenable to flushing.	Preferential pathways may allow even greater potential for off-site migration of contaminants and/or flushing solution. The separation of surfactants from recovered fluids for reuse is a major cost impact. Treatment of the recovered fluids results in process sludges and residual solids that would require treatment and disposal. Waste generation would cause more exposure risks to workers handling the materials and to communities along the transportation route (see Off-Site Disposal above).	High capital and low O&M costs.
		Solidification/Stabilization (S/S)	In this process, the soil is mixed with a binder that functions to physically entrap contaminants (solidification) and/or chemically react with contaminants to reduce their mobility (stabilization). The binder is typically delivered to the subsurface via auger mixing or high-pressure injection. The binder can consist of many materials, including Portland cement, bitumen, pozzolans, and polymers. The binder selection depends on compatibility with the contaminants at the site.	S/S would effectively immobilize inorganic contaminants. Leachability testing is usually performed to ensure the effectiveness of the process.	Since these areas primarily consists of waste rock, in-situ S/S would not be implementable due to difficulties with binder delivery and mixing.	Moderate capital and low O&M costs.
		Vitrification	In-situ vitrification (ISV) involves application of an electric current to produce very high subsurface temperatures to melt materials within the treatment zone. Innovative forms of this process, such as Planar ISV, incorporate moving electrodes that allow the melting process to begin at specified locations in the subsurface. Treatment can then be focused directly on the contaminated region, allowing greater treatment depths compared to conventional techniques. Organic contaminants and some volatile inorganic contaminants are destroyed or volatilized; off-gases are typically collected by a vacuum hood over the treatment area and treated prior to discharge. The electric current ends once the entire treatment zone becomes molten, then the treatment zone cools to form a vitrified mass. Inorganic contaminants are integrated into the mass and immobilized.	The migration of contaminants may be encouraged during treatment, when the soil is molten. However, the end product of ISV, a chemically-stable, leach-resistant glass and crystalline material, would effectively immobilize inorganic contaminants. Assessments to date demonstrate that the vitrified end-product appears to be unaffected by temperature cycling and other environmental stressors.	ISV can typically be implemented in a relatively short amount of time. However, it is extremely energy intensive. Moreover, the waste ore/rock, due to its large volume and generally coarse grain size, is not amenable to treatment via ISV.	High capital and low O&M costs.
Ex-Situ Treatment (assuming excavation)	Ex-Situ Physical/ Chemical Treatment	Chelation/Complexation	Chelation/complexation is mainly used for controlling the leaching of metals. It immobilizes metals by forming a stable bond, or complex, between a metal cation and a ligand (chelating agent). The stability of the chelation depends on the number of bonds formed between the chelating agents and the target cation: as the number of bonds increases, the stability of the resulting complex increases and so does the degree of immobilization of the metal contaminant within the complex. The efficiency of chelation/complexation is ion-specific and depends on the chelating agent, pH, and dosage.	Can be effective in reducing leachable metals concentrations to meet TCLP requirements, however, contaminant concentrations would not decrease. Treated material would then require disposal. Technology would require significant bench-scale studies to identify appropriate agents.	Implementable. Handling of any impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks could be mitigated through the use of PPE and other standard environmental protocols.	Moderate capital and low O&M costs.
		Physical Separation	Physical separation acts to concentrate contaminants into a reduced volume for subsequent treatment. Physical separation consists of sorting soil particles based on physical characteristics to reduce the volume of contaminated material. Most separation processes are based on one of the following physical characteristics: particle size, density, or magnetism.	The waste ore/rock material is not amenable to the physical separation process to isolate contaminants.	Implementable. Handling of any impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risk could be mitigated through the use of PPE and other standard environmental protocols.	Moderate capital and low O&M costs.
		Soil Washing	Soil washing concentrates contaminants into a reduced volume for subsequent treatment. Soil washing involves vigorously mixing contaminated soil with a wash solution, causing contaminants to be dissolved or suspended in the wash solution. The solution is then recovered and treated. Contaminants often bind to the finer fraction of a soil matrix (e.g., clay and silt), therefore soil washing often incorporates some type of physical separation process.	Soil washing is not applicable to the mineralogy of the waste piles.	Implementable. Site conditions such as steep slopes and shallow soils may impact implementability. The typically large grain size of the waste piles increases difficulty and slows progress. Handling of any impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks may be mitigated with use of PPE and other standard environmental protocols.	Moderate capital and low O&M costs.

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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
		Chemical Extraction	Chemical extraction concentrates contaminants into a reduced volume for subsequent treatment. Chemical extraction is similar to soil washing, but differs in that a chemical extractant, rather than a water-based solution, is used to encourage contaminant separation from the soil matrix. Acid extraction, which uses hydrochloric acid as an extractant, is commonly used to treat heavy metals. Hydrocyclones are used to separate the soil and extractant, which then undergo treatment/disposal.	This process option involves a form of re-mining of the waste material. The composition of the waste piles is not amenable to the mineralogy of the waste ore/rock.	Implementable. This process would produce a significant amount of residual sludge that would require transport to an off-site facility for treatment and disposal. Site conditions such as steep slopes and shallow soils may impact implementability. Handling of any impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks could be mitigated through the use of PPE and other standard environmental protocols.	Moderate capital and low O&M costs.
		Chemical Reduction/Oxidation	Chemical reduction/oxidation (redox) involves adding an oxidizing or reducing agent to the contaminated material, creating a redox reaction that results in a more stable, less toxic compound. Common oxidizing agents include ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.	Incomplete redox reactions and intermediate compounds may not improve and even worsen existing conditions. This process option is a reversible mechanism and would therefore be ineffective in reducing the volume, toxicity, and mobility of the impacted material. It would not provide long-term protection of human health and the environment.	Implementable. Site conditions such as steep slopes and shallow soils may impact implementability. The large size of the waste piles increases difficulty of application and slows progress. Handling of any impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks could be mitigated through the use of PPE and other standard environmental protocols.	Moderate capital and low O&M costs.
		Solidification/Stabilization (S/S)	In this process, the soil is mixed with a binder that functions to physically entrap contaminants (solidification) and/or chemically react with contaminants to reduce their mobility (stabilization). A pug mill or rotating drum mixer is commonly used to blend the soil with the binder. The binder can consist of many materials, including Portland cement, bitumen, pozzolans, and polymers. The selection of the binder depends on compatibility with the contaminants at the site.	S/S would effectively immobilize inorganic contaminants. Leachability testing is usually performed to ensure the effectiveness of the process.	Implementable. The need to crush the waste piles would hinder progress. Site conditions such as steep slopes and shallow soils may impact implementability. Handling of any impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks could be mitigated through the use of PPE and other standard environmental protocols.	Moderate capital and low O&M costs.
Resource Utilization	Resource Utilization	Resource Utilization	Resource utilization is analogous to re-mining the site. This process option involves transporting impacted waste piles to an off-site processing facility where metals would be recovered for use as a commercial product.	Resource utilization would facilitate the partial or complete removal of contaminant sources from the Site. Resource utilization would meet the potential cleanup goals at the Site by removing a source of surface and groundwater contamination. It would be effective in minimizing the amount of waste requiring treatment/disposal. However, the composition of the waste piles is not amenable to re-mining.	Handling of any impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks could be mitigated through the use of PPE and other standard environmental protocols. The potential for re-mining copper at the Site would likely be difficult to implement because of the physical and chemical composition of the waste piles. Therefore, this option is not considered feasible to implement.	Variable

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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
No Action	No Action	None	In accordance with CERCLA and NCP requirements, a No Action response must be developed to provide a baseline for comparison with other response actions. The "No Action" alternative includes only scheduled 5-Year Reviews to assess the alternative effectiveness and compliance with PRGs. It does not include any active or passive treatment of media, institutional controls, or monitoring.	May not meet the potential cleanup goals for the Site.	Implementable.	None.
Limited Action	Institutional Controls	Land Use Restrictions	A land use restriction is intended to prevent specific uses of or activities in order to minimize potential exposures to humans and the environment. Land use restrictions may be enacted to protect against potential hazards, to preserve a remedial action, or to restrict future land uses. Land use restrictions can be implemented by altering the deed or title of record or through re-zoning. These alterations would remain in effect in perpetuity, regardless of changes in property ownership.	May not meet the potential cleanup goals for the Site alone, but may be used in conjunction with other options. This process option would aid in deterring land use practices that would cause increased exposure risks to human receptors.	Implementable. Requires agreement by current land owner and possibly public acceptance.	Low capital and O&M costs.
		Informational/Educational Devices	Informational/educational devices consist of meetings or literature aimed at raising the public's knowledge of the site and addressing their concerns. Topics addressed may include the potential hazards posed by contaminants or encountered during implementation of the remedial alternative, or the purpose and effectiveness of the remedial actions.	May not meet the potential cleanup goals for the Site alone, but may be used in conjunction with other options. Informational/educational devices would effectively inform the public about the Site.	Implementable.	Low capital and O&M costs.
	Engineered Controls	Engineered Controls	Engineered controls are physical deterrents to restrict access, reducing the potential for exposure to contaminants. Fencing installed around the perimeter(s) of the source area(s) would prohibit human and animal access. Posted warnings identify potential hazards present at the Site and discourage trespassing and misuse. Security systems and patrols also deter trespassing and misuse.	May not meet the potential cleanup goals for the Site alone, but may be used in conjunction with other options. These items would effectively restrict access to the Site, thereby impeding the potential for exposure to contaminants.	Implementable; however, engineered controls may be difficult to maintain within the wetland complex.	Low capital and O&M costs.
Limited Action	Monitored Natural Recovery	Monitored Natural Recovery	Monitored natural recovery (MNR) uses naturally occurring processes such as dilution, volatilization, biodegradation, and sorption, to address contamination. While MNR cannot degrade inorganic contaminants, it may transform them into states that pose a relatively low risk to potential receptors. Metals precipitation, sorption of contaminants onto soil particles or into the soil matrix, and partitioning into organic matter reduce the mobility and bioavailability of contaminants. Redox reactions can transform the valence states of some inorganic contaminants into less soluble, and consequently less mobile, and/or less toxic forms.	Natural processes could be used to attenuate the contaminants of concern at the Site. However, significant modeling would be necessary to ensure that off-site migration of contaminants would not occur and that exposure pathways would not be completed prior to acceptable levels being reached. The permanence of the attenuation mechanism must also be evaluated to ensure that the mechanism would not be reversible. Long-term monitoring is required to confirm effectiveness. MNR may be effective in combination with source control measures.	Implementable. Does not involve any intrusive activities. MNA would be a long-term process, during which time the Site may not be available for productive use. Land use restrictions and/or engineered controls may also need to be implemented in conjunction with MNR to protect human health.	Low capital and low O&M costs.
Containment	Vertical Barriers	Sealable Joint Sheet Piling	A sealable joint sheet piling system can be used for containment. The sheet piling is installed using the same equipment and techniques as conventional pile driving. To prevent water and dissolved contaminants from flowing underneath, the sheet pile wall is usually keyed into a unit that is capable of acting as an aquitard (e.g., bedrock or glacial till).	If implementable, this process option would effectively contain surface water at the Site. Sealable joint sheet piling is an effective containment technique, but does not remove or treat the contaminants present in the surface water.	Subsurface obstructions and lack of sufficient overburden to support the wall restrict implementability. This option is not practical because there is not enough overburden soil to support a sheet pile wall; depth to bedrock is shallow.	High capital and low O&M costs.
	Collection	Surface Water Collection System	Diversion channels, retention ponds, trenches and other techniques are available to control surface water. Trenches and diversion channels effectively intercept and accumulate surface water. These water management techniques are typically used to: (1) direct water away from a particular area, such as an excavation or area of impact; (2) minimize erosion; and (3) collect surface water for equalization or treatment prior to discharge.	Effective as a component of a water treatment system.	Implementable. An extensive collection, pumping, and transport system would be required to collect surface water, and transport it to a flow equalization tank and from there to the treatment system. The equalization basin would have to be very large to even out the anticipated flow range. Site conditions such as steep slopes, shallow soils, and surface water hydraulics may impact implementability.	Low-moderate capital and low O&M costs.

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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
Ex-Situ Treatment	Active Vertical Barriers Ex-Situ Physical/ Chemical Treatment	Neutralization	Common neutralizers include limestone and hydrated lime, calcium oxide, kiln dust, trapzene, calcium hydroxide, caustic soda, soda ash, and ammonia. All can be used in mechanized systems to increase the pH of the waste stream and cause the precipitation of metals such as iron, manganese, and aluminum. The choice of chemicals to be used depends on the chemical characteristics of the impacted surface water and site accessibility.	Alkaline chemicals have been shown to be effective in treating ARD; bench/pilot scale testing required to demonstrate effectiveness of particular chemical. Unlikely to meet potential cleanup goals alone, but could be used as a component of a water treatment system.	Readily implementable as pretreatment for other process options. An extensive collection and pumping system would be required. Site conditions such as steep slopes and shallow soils may impact implementability, and surface water hydraulics and hydrologic conditions will affect system design. Neutralization systems require monitoring and maintenance, and some chemicals, such as caustic soda and ammonia, are dangerous to handle.	Low capital costs, moderate O&M costs.
		Precipitation/ Coagulation/ Flocculation	During the precipitation process, very fine particles are suspended by electrostatic surface charges, which create repulsive forces that prevent aggregation and reduce the effectiveness of solid-liquid separation processes. Coagulants and flocculation are used to increase particle size through aggregation to enhance precipitation. Common coagulants include inorganic electrolytes (alum, lime, ferric chloride, and ferrous sulfate), organic polymers, and synthetic polyelectrolytes. Polymers, in particular cationic polymers, can interfere with some treatment systems, and this must be taken into account if a polishing step will be needed. After coagulant addition, the water is mixed in slow-mix reactors (flocculators) to promote contact between the particles and flocculant settling. As flocculation occurs, the particles increase in mass and settle out of solution.	Effectiveness of the system relies on adequate solids separation techniques (e.g., flocculation, clarification, and/or filtration). Polymer would be needed to achieve adequate settling of solids. This process generates significant waste streams and would require significant power requirements. Unlikely to meet potential cleanup goals alone, but could be used as a component of a water treatment system. Polymers may hinder RO membranes; pilot testing required.	Implementable. Labor intensive and specialized skills would be required to operate the equipment. An extensive collection and pumping system would be required. Site conditions such as steep slopes, shallow soils, and surface water hydraulics may impact implementability.	Moderate capital costs, high O&M costs
		Filtration	Flocculation is typically followed by filtration, which involves passing water through filtration media at low speed. Sand or other granular material is regularly used. The filter media allows water molecules and smaller particles to pass, but obstructs larger particles. To selectively filter out components of the water stream, a filter media such as activated alumina may be used to adsorb the contaminants. As with other water treatment technologies, the filtration process is typically repeated several times to remove as many contaminants as possible.	Filtration is, like reverse osmosis and distillation, a relatively slow process. It requires low water velocity through the system to achieve adequate contact with the filtration media and may require re-circulating the waste stream several times to attain the desired effluent.	Implementable. In comparison to other treatment technologies, such as reverse osmosis and distillation, filtration does not require a source of heat or pressure. Accordingly, filtration requires less energy, reducing overall costs. Also, less water is wasted in the filtration process in comparison to reverse osmosis or distillation, which improves process efficiency.	Moderate capital costs, high O&M costs
		Reverse Osmosis	If a semi-permeable membrane is placed between two separate solutions of differing concentration, water will migrate from the weaker solution through the membrane to the stronger solution until an equilibrium concentration is reached; this process is called osmosis. In reverse osmosis, pressure is exerted on the side with the concentrated solution (referred to as the concentrate) to force the water molecules across the membrane to the less concentrated side (referred to as the permeate). The pore spaces in the membrane are large enough to allow water molecules to pass, but obstruct ions and larger molecules. For instance, salt, fluoride, manganese, iron, lead, and calcium molecules would be excluded from passage and remain in the concentrate. However, reverse osmosis would not restrict molecules smaller than those of water from passing through.	Effective in treating ARD. Pretreatment for hardness and TSS removal would be required. Generates significant waste streams. Would require additional post treatment technologies to achieve potential cleanup goals. Maintenance of a reverse osmosis system typically involves periodic replacement of the membrane. The length of time between replacements depends on the characteristics of the concentrate (i.e., temperature, pressure, and concentration of dissolved solids). In general, increasing the water temperature enhances the efficiency of the system, depending on the membrane used. The pressure required for the system varies based on the contaminant type and concentration. As the contaminant concentration in the concentrate increases, the amount of pressure required to effectively operate the system will also increase.	Implementable. Would require two-stage reverse osmosis unit and evaporator to reduce volume of reject solution (which ranges from 10 to 15% of total flow). Labor intensive and specialized skills would be required to operate the equipment. An extensive collection and pumping system would be required. Site conditions such as steep slopes, shallow soils, and surface water hydraulics may impact implementability.	High capital costs, high O&M costs
		Distillation	In the distillation process, impacted water is heated until it reaches its boiling point and begins to vaporize. The water is maintained at that temperature until all of the water has vaporized. The water vapor then travels through a condensation coil where it is cooled, condensed back into liquid form, and discharged into a receiving tank. A chiller and/or cooling tower is required to condense the steam. It is important to note that contaminants with boiling points equal to or lower than that of water will not be removed by this process. Constituents with high boiling points such as metals remain in the original tank in the form of sediment. The process is commonly repeated several times to achieve greater water purity.	Effective. Pretreatment for hardness removal would be required. Distillation is an energy-intensive and relatively slow process, particularly when the water needs to be treated several times to achieve treatment goals. The increased hydrogen content of the treated water tends to cause it to be acidic. Process would generate significant waste streams and have significant power requirements. Unlikely to meet potential cleanup goals alone, but could be used as a component of a water treatment system.	Implementable. Maintenance of a distillation unit includes cleaning out and disposing of the metals-containing sediment on the boiler side of the unit. Sediment disposal may be expensive due to the need to meet LDR requirements. May have material compatibility problems (i.e., require use of high nickel alloy instead of stainless steel). Would require a major cooling water source to condense the steam; highly energy intensive. Labor intensive and specialized skills would be required to operate equipment. An extensive collection and pumping system would be required. Surface water hydraulics and hydrologic conditions would impact implementability.	Very high capital costs, high O&M costs

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Ex-Situ Treatment	Active Vertical Barriers Ex-Situ Physical/ Chemical Treatment	Adsorption via Activated Alumina	Activated alumina is a common adsorbent that is made by industrially processing aluminum ore to generate a highly porous and adsorptive medium with substantial surface area. It can be employed to adsorb a variety of contaminants, most notably, fluoride, arsenic, and selenium.	Pretreatment for hardness removal would be required. Would generate significant waste streams and have significant power requirements. Activated alumina is not flexible and cannot be modified to site contaminants like ion exchange resins. Data not currently available to support the use of this technology for heavy metals removal, except for arsenic and fluoride. Therefore, effectiveness not demonstrated for Pike Hill Copper Mine Site.	Implementable. Activated alumina likely would require regeneration off-site, and would need to be replaced after only 10 regenerations. Most suitable as a post-treatment technology. Labor intensive and specialized skills would be required to operate the equipment. An extensive collection and pumping system would be required. Site conditions such as steep slopes, shallow soils, and surface water hydraulics may impact implementability.	High capital costs, high O&M costs
		Electrodialysis	Electrodialysis involves the movement of ions across alternating cation and anion exchange membranes in response to an applied electrical current. When a feed solution containing both positive and negative ions is passed through the membrane stack to which a voltage has been applied, the ions migrate towards their respective electrodes. The cation exchange membranes allow the cations to pass while inhibiting the anions, and the anion exchange membranes allow the anions to pass while inhibiting the cations. This process creates streams of dilute ion concentration (diluent) and streams rich in ion concentration (concentrate). An ionic rinse solution is circulated past the electrodes to maintain conductivity of the membrane stack while preventing potentially corrosive ions from the feed solution from contacting the electrodes.	Effective in treating ARD. Would require pre-treatment to handle elevated hardness and provide TSS removal. Would generate significant waste streams, have significant power requirements, and would require additional post-treatment technologies to achieve potential cleanup goals for the site.	Implementable. However due to nature of site ARD this technology would be unfavorable to implement; vendors for this technology application are not readily identified.	High capital costs, high O&M costs
		Ion Exchange	Ion exchange is a chemical reaction wherein an ion from solution is substituted for a similarly charged ion on the exchange resin. Ion exchange resins consist of synthetic organic polymers that contain ionic functional groups to which exchangeable ions are attached. Inorganic or natural polymeric materials, such as zeolites, may also be used. However, synthetic organic resins are typically preferred because their characteristics can be tailored to specific applications. The maximum number of exchanges per unit of resin depends on the number of mobile ion sites, which differs from resin to resin (REMCO, 2005). After the resin capacity has been exhausted, the resins can be regenerated for reuse.	Effective. Would require pre-treatment to handle elevated hardness and to provide TSS removal. Would generate significant waste streams and have significant power requirements. Roughing ion exchange canisters would be installed upstream of polishing resin canisters.	Implementable. The regenerant solution would have to be treated via evaporation to reduce the volume to be manifested off site. Labor intensive and specialized skills would be required to operate the equipment. An extensive collection and pumping system would be required. Site conditions such as steep slopes, shallow soils, and surface water hydraulics may impact implementability.	High capital costs, high O&M costs
Ex-Situ Treatment	Passive Ex-Situ Physical/ Chemical Treatment	Settling Ponds	Settling ponds are used to collect treated or partially treated waters discharging from an open limestone channel (OLD) or anoxic limestone drain (ALD). These ponds allow iron and other precipitates to settle and provide a more constant flow rate into a downgradient treatment. Settling ponds should be sized to allow a retention time of approximately 14 days.	Effective for allowing iron and other precipitates to settle and equalizing flow. Aeration required for iron removal. To achieve aeration by passive means, site must have sufficient topographic relief and area to allow for a number of small settling ponds in series. Passive oxygenating structures such as riffles are then placed in between each pond. Unlikely to meet potential cleanup goals alone, but could be used as a component of a water treatment system.	Implementable. Site conditions such as steep slopes, shallow soils, and surface water hydraulics may impact implementability.	Moderate capital and O&M costs.
		Diversion Wells with Limestone Treatment	This system is useful for treating small ARD streams. It uses wells (1.5 to 1.8 m in diameter and 2 to 2.5 meters deep) made of concrete or metal and filled with limestone. The waste stream flows through a pipe to the bottom of the well, is discharged, and then flows up through the limestone. Water flow through the well is designed to be sufficiently turbulent to prevent the coating of the limestone with iron precipitate.	Dissolution of limestone adds alkalinity and raises pH. Iron and metal precipitate coating is prevented by turbulence of the flow through the well, although periodic limestone replenishment is needed. Because the limestone needs to be replaced frequently, these systems are not entirely passive. Because they lack settling ponds, diversion wells work best for water with low metal concentrations; this may limit their effectiveness at the Site. For some ARD sources, unlikely to meet potential cleanup goals alone, but could be used as a component of a water treatment system.	Implementable. Site conditions such as steep slopes, shallow soils, and surface water hydraulics may impact implementability.	Moderate capital and O&M costs
		Successive Alkalinity Producing System (SAPS)	The goal of a SAPS is to add alkalinity to ARD and then precipitate iron hydroxides upon subsequent oxygenation, using two separate steps to limit iron hydroxides from armoring the limestone. A SAPS is a variant of the anaerobic systems used mainly to treat coal mine drainage. SAPS can be designed specifically for those instances that are not appropriate for ALDs (i.e., waters with DO concentrations greater than 5 mg/L and high concentrations of oxidized Fe+3).	Effective. Must be followed by a settling pond to allow iron hydroxides to precipitate. May require several treatment cells in series to eliminate short-circuiting. Uniform flow rates and even flow distribution through the substrate are critical for effective SAPS bioreactor treatment. Can be difficult to ensure that anoxic conditions are maintained; would require alkalinity addition as a buffering agent. Bench/pilot-scale testing would be required. Likely would need to be combined with additional treatment technology/technologies to meet potential cleanup goals.	Implementable, simple construction. Difficult to maintain and still preserve anaerobic conditions. Surface water hydraulics and hydrologic conditions would impact implementability.	Moderate capital costs, moderate O&M costs

Table 7-2
Screening of Potential Treatment Options for Surface Water
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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
Ex-Situ Treatment	Active Ex-Situ Biological Treatment	Sulfate-Reducing Bacteria (SRB) Bioreactors	The chemical processes in anaerobic bioreactors are bacterial oxidation of organic matter with concomitant reduction of DO, ferric iron (Fe+3), and sulfate. Because sulfate-reducing bacteria (SRB) play a major role in this type of bioreactor, the anaerobic bioreactor is often called an SRB bioreactor. As sulfate is reduced, the produced sulfide reacts with iron, copper, zinc, and cadmium to form metal sulfides. Reduction occurs in the absence of oxygen, which requires that flow be uni-directional and preferably vertical throughout the organic bioreactor substrate within the subsurface.	Effective. Must contain an environment that allows an entire consortium of microorganisms to prosper; a pH of 5.5 or higher is preferred. Uniform flow rates and even flow distribution through the substrate are critical. The bioreactor must be appropriately engineered to maximize vertical flow and minimize short-circuiting. Anaerobic systems are sensitive to temperature changes, substrate changes, and pH changes. Seasonal low temperatures may limit effectiveness at the Site may be limited. Potential for discharge of excess sulfide to receiving streams.	Implementable. Flow equalization required. System difficult to maintain and still preserve anaerobic conditions. Site conditions such as steep slopes, shallow soils, and surface water hydraulics may impact implementability.	Low-moderate capital costs, moderate O&M costs
		Liquid-Reactant (Semi-active) Bioreactors	In a liquid-reactant bioreactor, an alcohol such as methanol, ethanol, or ethylene glycol is added at a controlled rate based on the stoichiometric relation between the alcohol and the sulfate being reduced. Sodium hydroxide is also added to adjust the pH. The reaction rate can be better controlled than in an SRB.	Effective. Overcome problems with SRB bioreactors related to decreased permeability over time, decreasing reaction rates over time, and freezing in the winter months. Sizing of the system for effective treatment is dependent on sulfate loading, metal loading, residence time, and water acidity levels.	Implementable. Flow equalization required. System difficult to maintain and still preserve anaerobic conditions. Site conditions such as steep slopes, shallow soils, and surface water hydraulics may impact implementability.	Low-moderate capital costs, high O&M costs
In-Situ Physical/ Chemical Treatment	Active In-Situ Physical/ Chemical Treatment	Contact Treatment Application	A chemical reagent such as lime, Bauxsol, or molasses can be added directly to a standing water body to precipitate out metals. The amount of reagent applied would depend on the composition of the pit lake water and the desired quality of the treated water. Reagent blends and application strategies could be varied to achieve the desired treated water quality. Computer modeling is typically used to select the most appropriate blend and required addition rates, followed by laboratory trials.	Short-term effectiveness is high; one-time application of reagent (i.e., lime, Bauxsol, molasses) treats water column. The precipitate forms a blanket of sediment on the bottom of the water body. If left in place, this layer acts to separate the stored acidity and trace metals in the sediment from the surface water. Metals retained in reactive media reportedly remain chemically bound to media and if removal is necessary, the material can be handled as a non-hazardous waste. However, long-term effectiveness is limited at the Site due to continued runoff of ARD and neighboring waste piles. Continuous applications would be required to be effective.	Implementable, but the need for continuous applications at the Site would render this option impractical.	Moderate capital costs, high O&M costs
		Reactive Media Contact Cells	Treatment cells are constructed of vessels filled with reactive media such as limestone, Bauxsol, apatite or EHC-M. Impacted water is passed through a cell or a series of cells. The medium neutralizes the acid in the ARD and removes metals from the water, binding them into a highly stable form. The metals are bound to the reactive medium and spent material can be handled as a non-hazardous waste. For some media, the water is mechanically aerated prior to contact with the pellets to ensure that the dissolved oxygen (DO) concentration is higher than saturation to enhance performance efficiency.	Effectiveness depends on treatment media used in cell (e.g., limestone, Bauxsol or apatite) and on water chemistry. A treatability study would be required. May require use in combination with additional treatment technology to meet effluent standards.	Implementable. Surface water hydraulics and geochemistry would impact implementability.	Moderate capital costs, low-moderate O&M costs
	Passive In-Situ Physical/ Chemical Treatment	Anoxic Limestone Drains (ALDs)	An ALD is a trench filled with crushed high-calcium limestone, sealed with geotextile or plastic, and covered with clay or soil to prevent oxygen inflow. It is typically built into a hillside or tailing pile to capture ARD that has not yet been exposed to oxygen. As the acidic water flows through the ALD, the acid dissolves some of the limestone, which adds alkalinity to the water and raises the pH.	Dissolution of limestone adds alkalinity and raises pH, but coating of limestone by iron and aluminum precipitates can reduce the performance over time, especially in low flow conditions. Requires removal of DO and Fe3+ before treatment. Problems with long term effectiveness include difficulty in maintaining anoxic conditions within the drains. Unlikely to meet potential cleanup goals alone, but could be used as a component of a water treatment system. Effectiveness at the Site may be limited due to seasonal low temperatures.	Implementable. Difficult to maintain anaerobic conditions. Surface water hydraulics and hydrologic conditions would impact implementability.	Moderate capital and O&M costs.
		Open Limestone Channels (OLCs)	The OLC is a variant of the ALD and is used to treat discharges that are oxygenated and contain Fe+3 or high aluminum content. The OLC can be effective in adding alkalinity to ARD and raising the pH. However, OLCs require an environment that will self-scour the exposed limestone surface. OLCs must have significant vertical gradient to allow for turbulent flow to strip off precipitates and must contain a number of small ponding areas between turbulent points to collect the resultant precipitates.	Effective for treatment of discharges that are oxygenated and contain Fe+3 or high aluminum content. Effective in adding alkalinity to ARD and raising the pH. Scouring limestone with high pressure spray system with heat trace would be necessary to reduce armoring of limestone and increase effectiveness. Effectiveness at the Site may be limited due to seasonal low temperatures.	Implementable. While cover would minimize precipitation infiltration and help protect from freezing, OLC must be open to oxygen. Multiple channels could be installed with different elevations to successively handle increasing flows. Shallow soils may impact implementability. Systems with sufficient topographic relief (between 45 and 60 percent slopes) are more cost-effective, more easily monitored, and more effective. Surface water hydraulics and hydrologic conditions would impact implementability.	Moderate capital costs, moderate O&M costs

Table 7-2
Screening of Potential Treatment Options for Surface Water
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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
In-Situ Physical/ Chemical Treatment (cont.)	Passive In-Situ Physical/ Chemical Treatment (cont.)	Lime Dosing Wheel	Lime dosing systems uses water wheels to drive an auger that adds lime pellets to the ARD stream at precise dosing levels proportional to the ARD flow rate. Following dosing, the effluent is aerated and metals are precipitated in a settling basin or tank. The system supplies alkalinity along with aeration to precipitate metals as oxides and hydroxides. The system operates solely on water power, operates 24-hours per day, and requires only periodic monitoring.	Effective at removing metals including aluminum, copper, iron, manganese, and zinc. Maintaining proper hydraulic residence time is one of the most important design factors for effective treatment.	Implementable, simple construction. Operational problems reported associated with clogging of the inlet with iron hydroxides, and accumulation of granular lime below the dispenser.	Low capital and moderate O&M costs
		Limestone Sand Treatment	This option involves the periodic placement of limestone sand in the headwaters of an ARD-impacted stream. During periods of high flow, the current carries the sand downstream, where it mixes with natural sediments and increases the pH. The sand must be replenished frequently depending on flooding frequency. Limestone sand addition is most effective for streams that have low pH, but also relatively low dissolved metal concentrations. Iron and/or aluminum hydroxides precipitate in the stream, but probably over a shorter stretch than without treatment. Particle size, purity, and mass of the limestone are important considerations for successful treatment.	Effective in neutralizing acid in stream; coating of limestone particles with iron oxides can occur, but the agitation and scouring of limestone in the streambed keeps fresh surfaces available for reaction. Replenishing the limestone sand is needed at least twice a year, and may be more often depending on site conditions. Most effective application would be just prior to spring runoff flows. Unlikely to meet potential cleanup goals alone, but could be used as a component of a water treatment system.	Readily implementable during all but winter months. Sediments would require periodic removal, dewatering and disposal.	Low capital and high O&M costs
	Passive In-Situ Biological Treatment	Constructed Aerobic Wetlands	Aerobic wetlands are typically shallow excavations with one to two feet of soil, gravel, and/or rocks in a hummocky pattern. The designed hummocks allow for variations in water depth of between one inch and approximately one foot to form a diversity of microenvironments. Aerobic wetlands are often constructed as a series of terraced cells with intermediate spill points and typically contain planted areas and open water zones. Iron and manganese oxidation, precipitation, and sorption to biomass occur in the wetland.	Effective as a component of water treatment system; would not generally address potential cleanup goals as a sole treatment process. Often included as a final process step in system containing other passive treatment methods (e.g., ALDs, OLCs, and/or anaerobic bioreactors.) Have been used to successfully treat manganese, which will pass through ALDs, OLCs, and SRB bioreactors. Effectiveness at the Site may be limited because seasonal low temperatures may cause dormancy, and the system may go anaerobic when iced over. Potential for discharge of excess sulfide to receiving stream.	Implementable. COCs in surface water would prohibit use as primary treatment. Space requirements would be significant. Site conditions such as steep slopes and shallow soils may impact implementability. Surface water hydraulics and hydrologic conditions would impact implementability.	Moderate capital and low-moderate O&M costs
		Phytoremediation	Phytoremediation is an emerging technology in which vegetation is used to extract inorganic contaminants from soil or water. The technology requires a long residence time for the water to contact the vegetation.	Due to the harsh climate and the long residence time requirements, this technology will not be considered for treatment of surface water/sediment.	Implementable; however, plants selection would depend on hardiness of the plants; may need reseeding/ revegetation. Institutional controls would be required in order to protect the plants against dangerous land uses as well as to prevent potential receptors from contacting the plants.	Moderate capital and low-moderate O&M costs

Table 7-3
Screening of Potential Treatment Options for Sediment
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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
No Action	No Action	No Action	In accordance with CERCLA and NCP requirements, a No Action response must be developed to provide a baseline for comparison with other response actions. The "No Action" alternative includes only scheduled 5-Year Reviews to assess the alternative effectiveness and compliance with OU1 PRGs. It does not include any active or passive treatment of media, institutional controls, or monitoring.	May not meet potential cleanup goals specified for the Site.	Implementable.	Low. Include periodic monitoring and 5-year reviews.
Limited Action	Institutional Controls	Land Use Restrictions	A land use restriction is intended to prevent specific uses or activities in order to minimize potential exposure to humans and the environment. Land use restrictions may be enacted to protect against potential hazards, to preserve a remedial action, or to restrict future land uses. Land use restrictions can be implemented by altering the deed or title of record or through re-zoning. These alterations would remain in effect in perpetuity, regardless of changes in ownership of the property.	May not meet cleanup goals alone, but may be used in conjunction with other options. This process option would aid in deterring land use practices that would cause increased exposure risks to human receptors.	Implementable. Requires agreement by current land owner and possibly public acceptance.	Low capital and O&M costs.
		Informational/ Educational Devices	Informational/educational devices consist of meetings or literature aimed at raising the public's knowledge of the site and addressing their concerns. Topics addressed may include the potential hazards posed by contaminants or encountered during implementation of the remedial alternative, or the purpose and effectiveness of the remedial actions.	May not meet cleanup goals for the Site alone, but may be used in conjunction with other options. Informational/ educational devices would effectively inform the public about the Site.	Implementable.	Low capital and O&M costs.
	Engineered Controls	Engineered Controls	Engineered controls are physical deterrents that serve to restrict access to the site, thereby impeding the potential for exposure to contaminants. Fencing could be installed around the perimeter(s) of the source area(s) to prohibit human and animal access to the area. Posted warnings identify potential hazards present at the Site and discourage trespassing and misuse. Security systems and patrols also deter trespassing and misuse.	May not meet potential cleanup goals specified for the Site as the sole application, but may be used in conjunction with other options. These items would effectively restrict access to the Site, thereby impeding the potential for exposure to contaminants.	Implementable; however, engineered controls may be difficult and costly to maintain within PHB and the wetland complex.	Low capital and O&M costs.
Limited Action	Monitored Natural Recovery	Monitored Natural Recovery (MNR)	MNR would leave contaminated sediments in place to allow for ongoing aquatic, sedimentary, and biological processes to contain, destroy, or otherwise reduce the bioavailability of the contaminants. MNR differs from "no action" alternatives in that source control, assessment, modeling, and monitoring efforts are required to verify that remediation (i.e., environmental processes to permanently reduce risk) is occurring.	Natural processes could be used to immobilize the contaminants of concern at the Site. However, significant modeling would be necessary to ensure that downstream migration of contaminants would not occur. It would also be necessary to demonstrate that the mechanism that would immobilize the contaminants (if any) would not be reversible.	Implementable. MNR may require a long timeframe to achieve the potential cleanup goals specified for the Site. Institutional controls and/or engineered controls may need to be implemented with MNR to protect human health. A long-term sediment quality monitoring program would be required to track changes to sediment quality over time.	Low capital and O&M costs.
Containment	Engineered Capping	Natural Material Capping (e.g., riprap)	Impacted sediments remain in-situ and are covered by a non-synthetic media (i.e., sand, riprap) sized to provide erosion protection compatible with stream velocities. Thickness of cap is dependent on nature of COCs in-situ but must be sufficient to isolate impacted sediments from benthic communities.	While this technology could be used to effectively isolate sediment from potential ecological receptors, verification of the process effectiveness could be difficult. Effectiveness could be impaired by freeze-thaw process, wetting-drying process, and high flow velocity scour events.	Not readily implementable. Requires detailed pre-design and design analyses to select material and determine placement. Required increase in sediment bed thickness associated with process may limit implementability in small channels and channels with minimal flow areas and wetted perimeters. Surface water hydraulic and hydrological conditions (e.g., steep gradients) could impact implementability.	Moderate capital costs, low to moderate O&M costs
		Synthetic Material Capping (e.g., Aqua-Block, FabriForm)	A synthetic cap is similar to a natural cap, however, impacted in-situ sediments are covered with synthetic non-natural material that encapsulates the media, providing protection from migration and isolation from benthic environment. Cap materials include concrete (or similar) or engineered composite material (i.e., Aqua Block).	As with natural capping material, this technology could be used to effectively isolate sediment from potential ecological receptors. However, effectiveness could be impaired by freeze-thaw process, wetting-drying process, and high flow velocity scour events.	Not readily implementable. Requires detailed pre-design and design analyses to select the material and determine placement. Required increase in sediment bed thickness associated with process may limit implementability in small channels and channels with minimal flow areas and wetted perimeters. Surface water hydraulic and hydrological conditions (e.g., steep gradients) could impact implementability.	High capital and O&M costs

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Screening of Potential Treatment Options for Sediment
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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
Removal and Disposal	Excavation	Hydraulic Dredging	Hydraulic dredging employs equipment that loosens the sediment then vacuums it into a collection/storage vessel.	This technology could be effective in removing sediments from streams. Engineering controls would be required to limit mobilization of sediments into surface water, resulting in transport further downstream.	Not implementable for scale of tributaries with impacted sediments within project watersheds.	Very high capital and low O&M costs.
		Mechanical Dredging	Mechanical dredging utilizes physical processes to excavate impacted sediment. Recovered sediments then undergo treatment/disposal as necessary.	This technology could be effective in removing sediments from streams. Engineering controls would be required to limit mobilization of sediments into surface water, resulting in transport further downstream.	Implementable for scale of impacted tributaries within project watershed. Surface water hydraulic and hydrological site conditions would impact implementability. Access may be difficult in the wetland complex.	Low capital and low O&M costs.
Removal and Disposal	Water Disposal (assuming dredging)	Open-Water or In-Water Disposal	Open-water disposal uses earthen and/or synthetic materials to cover impacted sediments, thereby isolating them from the environment. The cap can be constructed over sediments that are left in place or over sediments that have been dredged and deposited.	Capping does not aim to reduce the volume or toxicity of the contaminants; it impedes migration. Capping also mitigates the potential for exposure by human and ecological receptors, benthic organisms in particular.	Not implementable for scale of tributaries with impacted sediments within project watersheds.	Moderate capital and O&M costs.
	Land Disposal (assuming dredging)	On-Site Consolidation	For on-site consolidation, dredged material would be brought back to the Site (for off-site material) and incorporated into an engineered containment cell within the remedial area.	An on-site consolidation cell would be effective in preventing exposures to human and environmental receptors. The long-term effectiveness and permanence of the cell would require suitable engineering design, the implementation of land use restrictions, and the implementation of a groundwater monitoring program.	Sediments would likely require dewatering with possible treatment/disposal of the decant water. In comparison to off-site disposal, on-site consolidation of waste materials would involve less exposure risk to workers and the surrounding community because the waste material would require less handling and no transport of materials off-site would be involved. Haulage roads at the Site may need to be improved or constructed to facilitate material transport.	High capital and moderate O&M costs.
Removal and Disposal	Land Disposal (assuming dredging)	Off-Site Disposal	This process option consists of the transport of dredged material from the Site to a licensed, off-site disposal facility.	This process option is applicable to the contaminants present at the Site. Off-site disposal would remove the contaminants from the Site for placement in a permitted, offsite disposal facility, thereby preventing exposure to human and environmental receptors.	Impacted sediments exhibit potentially leachable metals concentrations. The sediment may require dewatering prior to disposal, and the decant water would also require treatment/ disposal. Workers handling the material and communities along the transportation route would be exposed to increased risk, which would be mitigated through the use of PPE, equipment decontamination prior to leaving the Site, and tarped truck beds. Haulage roads at the Site may need to be improved or constructed to facilitate the material transport.	High capital and no O&M costs. Assumes hazardous waste landfill
Ex-Situ Treatment (assuming dredging)	Ex-Situ Biological Treatment	Phytoremediaton	Phytoremediation employs specifically selected plants to remove, store, or reduce the toxicity of contaminants. While high contaminant concentrations can be toxic to most plants, hyperaccumulator plants have the ability to handle significant amounts of inorganic contaminants. Phytoremediation is applicable to a wide range of inorganic contaminants.	The effectiveness of this technology, in general, would be driven by the ability to find plants that are compatible with the types of contaminants, contaminant concentrations, and local climate. Phytoremediation would only be effective in remediating contamination within reach of the plant roots.	Contaminant concentrations may be too high for successful plant growth. Plant growth may be hindered by acidic soil conditions due to ARD. Bioavailability of metal species would need to be assessed. Institutional controls would need to be implemented to protect the plants from wildlife as well as to prevent potential receptors from contacting the plants.	Low to moderate capital and moderate O&M costs.
		Enhanced Bioremediation	Enhanced bioremediation uses amendments to stimulate microorganisms, enabling them to convert contaminants into less harmful forms. Bioremediation cannot degrade inorganic contaminants, however, it can be used to change their valence state, resulting in adsorption, immobilization and accumulation of inorganics in microorganisms.	This technology may transform inorganic contaminants into states exhibiting decreased mobility, bioavailability, and toxicity, although high concentrations of heavy metals may be toxic to the microorganisms. The rate at which bioremediation occurs will decrease in colder temperatures.	Implementable. Sediment pH may adversely affect microorganism population. Handling of any impacted material would increase risks of exposure to workers. These risks could be mitigated through the use of PPE and other standard environmental protocols.	Low capital and moderate O&M costs.
	Ex-Situ Physical/ Chemical Treatment	Chelation/ Complexation	Chelation/complexation is mainly used for controlling the leaching of metals. This process immobilizes metals by forming a stable bond, or complex, between a metal cation and a ligand (chelating agent). The stability of the chelation depends on the bonds formed between the chelating agents and the target cation: as the number of bonds increases, the stability of the resulting complex and therefore the degree of immobilization also increases. Process efficiency is ion-specific and depends on the chelating agent, pH, and dosage.	Can be effective in reducing leachable metals concentrations to meet TCLP requirements, however, contaminant concentrations would not decrease. Treated material would then require disposal. Technology would require significant bench-scale studies to identify appropriate agents.	Implementable. Sediment dewatering may be required, generating potentially impacted liquid waste stream. Handling of any impacted material at the Site would increase risks of exposure to workers. These risks could be mitigated through the use of PPE and other standard environmental protocols.	Moderate capital and low O&M costs.
		Soil Washing	Soil washing concentrates contaminants into a reduced volume for subsequent treatment. Soil washing involves vigorously mixing contaminated soil with a wash solution, causing contaminants to be dissolved or suspended in the wash solution. The solution is then recovered and treated. Contaminants often bind to finer materials (e.g., clay and silt), therefore, soil washing often incorporates a physical separation process.	Not applicable to the sediment mineralogy.	Implementable. Handling of any impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks could be mitigated through the use of PPE and other standard environmental protocols.	Moderate capital and low O&M costs.

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Screening of Potential Treatment Options for Sediment
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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
		Chemical Extraction	Chemical extraction concentrates contaminants into a reduced volume for subsequent treatment. Chemical extraction is similar to soil washing, but differs in that a chemical solvent or surfactant is used to promote contaminant separation from the soil matrix. Acid extraction, which uses hydrochloric acid, is commonly used to treat heavy metals. Hydrocyclones are used to separate the soil and extractant, which then undergo treatment/disposal.	This process option involves a form of re-mining of the waste material. The composition of the sediment is not amenable to the mineralogy of the sediment.	Implementable. This process would produce residual sludge that would require transport to an off-site facility for treatment and disposal. Handling of any impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks could be mitigated through the use of PPE and other standard environmental protocols.	High capital and low O&M costs.
		Chemical Reduction/Oxidation	Chemical reduction/oxidation (redox) involves adding an oxidizing or reducing agent to the contaminated material, creating a redox reaction that results in a more stable, less toxic compound. Common oxidizing agents include ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.	Incomplete redox reactions and intermediate compounds may not improve and even worsen existing conditions. This process option is a reversible mechanism and would therefore be ineffective in reducing the volume, toxicity, and mobility of the impacted material. It would not provide long-term protection of human health and the environment.	Implementable. Handling of impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks could be mitigated through the use of PPE and other standard environmental protocols.	Moderate capital and low O&M costs.
		Solidification/Stabilization	In this process, the soil is mixed with a binder to physically entrap contaminants (solidification) and/or chemically react with contaminants to reduce their mobility (stabilization). A pug mill or rotating drum mixer is commonly used to blend the soil with the binder. The binder can consist of many materials, including Portland cement, bitumen, pozzolans, and polymers. The selection of the binder depends on compatibility with the contaminants at the site.	Solidification/stabilization would effectively immobilize inorganic contaminants.	Implementable. Handling of impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks could be mitigated through the use of PPE and other standard environmental protocols.	Moderate capital and low O&M costs.
Resource Utilization	Resource Utilization	Resource Utilization	Resource utilization is analogous to re-mining the site. This process option involves transporting impacted wastes an, off-site process facility where metals would be recovered for use as a commercial product.	Resource utilization could meet potential cleanup goals at the Site by removing a source of contamination. It would be effective in minimizing the amount of waste requiring treatment/disposal. This process option could be used in conjunction with other remedial options for the Site.	Handling of impacted material at the Site would increase risks of exposure to workers as well as communities along the transportation route. These risks could be mitigated through the use of PPE and other standard environmental protocols. The potential for re-mining copper at the Site would likely be low because of the quality and low quantity of metal in the sediment. Therefore, this option is not considered feasible to implement.	High capital and no O&M costs.

Table 7-4
Screening of Potential Treatment Options for Groundwater/Mine Pools
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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
No Action	No Action	None	In accordance with CERCLA and NCP requirements, a No Action response must be developed to provide a baseline for comparison with other response actions. The "No Action" alternative includes only scheduled 5-Year Reviews to assess the alternative effectiveness and compliance with PRGs. It does not include any active or passive treatment of media, institutional controls, or monitoring.	May not meet the potential cleanup goals for the Site.	Implementable.	None.
Limited Action	Institutional Controls	Land Use Restrictions	A land use restriction is intended to prevent specific uses of or activities in order to minimize potential exposures to humans and the environment. Land use restrictions may be enacted to protect against potential hazards, to preserve a remedial action, or to restrict future land uses. Land use restrictions can be implemented by altering the deed or title of record or through re-zoning. These alterations would remain in effect in perpetuity, regardless of changes in property ownership.	May not meet the potential cleanup goals for the Site alone, but may be used in conjunction with other options. This process option would aid in deterring land use practices that would cause increased exposure risks to human receptors.	Implementable. Requires agreement by current land owner and possibly public acceptance.	Low capital and O&M costs.
		Informational/Educational Devices	Informational/educational devices consist of meetings or literature aimed at raising the public's knowledge of the site and addressing their concerns. Topics addressed may include the potential hazards posed by contaminants or encountered during implementation of the remedial alternative, or the purpose and effectiveness of the remedial actions.	May not meet the potential cleanup goals for the Site alone, but may be used in conjunction with other options. Informational/educational devices would effectively inform the public about the Site.	Implementable.	Low capital and O&M costs.
	Engineered Controls	Engineered Controls	Engineered controls are physical deterrents to restrict access, reducing the potential for exposure to contaminants. Fencing installed around the perimeter(s) of the source area(s) would prohibit human and animal access. Posted warnings identify potential hazards present at the Site and discourage trespassing and misuse. Security systems and patrols also deter trespassing and misuse.	May not meet the potential cleanup goals for the Site alone, but may be used in conjunction with other options. These items would effectively restrict access to the Site, thereby impeding the potential for exposure to contaminants.	Implementable.	Low capital and O&M costs.
Limited Action	Monitored Natural Recovery	Monitored Natural Recovery	Monitored natural recovery (MNR) uses naturally occurring processes such as dilution, volatilization, biodegradation, and sorption, to address contamination. While MNR cannot degrade inorganic contaminants, it may transform them into states that pose relatively low risk to potential receptors. Precipitation, sorption of contaminants onto soil particles or into the rock matrix, and partitioning into organic matter reduce the mobility and bioavailability of contaminants. Redox reactions can transform the valence states of some inorganic contaminants into less soluble, and therefore less mobile, and/or less toxic forms.	Natural processes could be used to attenuate the contaminants of concern at the Site. However, significant modeling would be necessary to ensure that off-site migration of contaminants would not occur and that exposure pathways would not be completed prior to acceptable levels being reached. The permanence of the attenuation mechanism must also be evaluated to ensure that the mechanism would not be reversible. Long-term monitoring is required to confirm effectiveness. MNR may be effective in combination with source control measures.	Implementable. Does not involve any intrusive activities. MNA would be a long-term process, during which time the Site may not be available for productive use. Land use restrictions and/or engineered controls may also need to be implemented in conjunction with MNR to protect human health.	Low capital and low O&M costs.
Containment	Vertical Barriers	Slurry Walls	Slurry walls are typically constructed by either filling a trench or injecting slurry into space created by a vibrating beam. The hardened slurry acts as a low-permeability barrier to groundwater flow. The slurry wall is usually keyed into a unit capable of acting as an aquitard in order to keep groundwater and contamination from flowing under the slurry wall. Slurry walls are often used with caps to impede groundwater movement.	Slurry wall effectiveness depends on the ability to install the structure into the media and key it into a base impervious layer.	Not implementable. Water containment would require lateral bedrock flow cutoff wall installations within deep zones of the surrounding bedrock (i.e. more than 100 feet below ground surface). Therefore, slurry walls would not be feasible in containing groundwater.	High capital and low O&M costs.
		Grout Curtain	A grout curtain is constructed by injecting grout into soil pore spaces or rock fractures via high-pressure injection points that are drilled into the geologic media. The emplaced grout solidifies, reducing the matrix hydraulic conductivity.	Grout curtain effectiveness depends on distribution of grout into pore spaces and fractures to cut off infiltration, and the ability to key the curtain into an impermeable layer. Grout could be injected into fractures within the bedrock adjacent to the underground workings; however, verification of effectiveness would require significant effort using advanced technologies. Groundwater could still enter the mine through seepage through the roof and floor; therefore, this technology would need to be combined with others to achieve RAOs.	A grout curtain would not be implementable as a remedial technology to address groundwater containment for the underground workings because of the requirement to create a grout curtain to the required depth (more than 100 feet deep) required for this application.	High capital and low O&M costs.
		Solidified Barrier	Solid material (such as aggregate) is injected/poured into the open space of the workings in a series of boreholes to create a "ridge" of material. Grout may then be injected to the top of the material in order for it to solidify. Several of these barriers may be installed to minimize the open flow of groundwater.	The effectiveness of the barrier would depend on the amount of material which could be added to fill the open void. The barrier would not be keyed into rock, and therefore may allow underflow and overflow. The mine pool would remain in place and could potentially serve as a source of contamination to the surrounding bedrock.	Implementable; however, the complexity of the workings may require a large number of injections to reach different levels. The steep surface topography may cause problems with drill rig access, requiring extensive access road construction.	High capital and low O&M costs.

Table 7-4
Screening of Potential Treatment Options for Groundwater/Mine Pools
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GRA	Technology	Process Option	Description	Effectiveness	Implementability	Cost
Containment	Vertical Barriers	Sheet piling	A sealable joint sheet piling system is constructed by driving a sheet pile wall to the target depth, typically keying the sheet piling into a unit which is capable of acting as an aquitard.	This technology would not be effective because it cannot be used for bedrock.	Not implementable for bedrock.	High capital and low O&M costs.
	Isolation/ Encapsulation	Grout Placement	Grout is used to isolate source material from contact with groundwater. Grout could be installed by injection points drilled from the surface along the alignment of the UW. In order to ensure that ARD sources were completely isolated from water and oxygen, the entire workings would be backfilled.	Grout would eliminate or significant limit contact of source material with groundwater and atmospheric oxygen, thereby significantly reducing or eliminating the potential for ARD generation. The use of grout may also raise the pH of seepage, which could further immobilize metals.	Safety and structural issues prevent mine entry to implement the technology, but the workings may be grouted from the surface. A PDI would be required to confirm the location and orientation of the workings at depth. Large volumes of grout would be required for implementation. Significant infrastructure would also be required.	High capital and low O&M costs.
Ex-Situ Treatment	Groundwater Pump and Treat	Mine Pool Hydraulic Seepage Controls	A groundwater extraction system would be located adjacent to each of the mine workings to reduce the infiltration of groundwater to the mine pool as well as the overall volume of water to be treated. Water originating from the hydraulic control extraction system is assumed to be clean and no treatment would be required for this volume. Once extracted, the water would be discharged to the surface.	Pump and treat could be used to permanently dewater the mine pool. The technology would need to be implemented in combination with extraction and treatment to dewater the mine pool, as well as extraction and treatment indefinitely thereafter to address the volume of ARD seepage into the mine pool that would bypass the hydraulic controls.	UW hydraulic controls would be difficult to implement because of the volume of water and the depths of extraction involved. Based on the low yield of the local bedrock aquifer, the resulting scale of the cone of depression and recharge capture zone would be expected to extend far offsite, potentially impacting local bedrock water supplies.	High capital and O&M costs.
		Mine Pool Plume Containment and Treatment	Groundwater pumping with ex-situ treatment and on-site disposal of treated groundwater involves pumping impacted groundwater through groundwater extraction wells. Once extracted, the water would require treatment using ex-situ treatment technologies and discharge to the surface.	Pump and treat could be used to reduce the bedrock aquifer to elevations below the mine pool and permanently dewater the mine pool. Water treatment would be required during dewatering of the mine pool and indefinitely thereafter.	Dewatering of the workings would be difficult to implement because of the volume of water involved. Treatment of extracted groundwater would be difficult to implement due to the high flow rates required to achieve mine pool dewatering and the complexity of the treatment system required to achieve surface water discharge criteria.	High capital and O&M costs.
In-Situ Treatment	Passive In-Situ Treatment	Sulfate-Reducing Bacteria Bioreactors	Passive treatment technologies include both bioreactors and contact-driven technologies (i.e. apatite, Bauxsol™). Although these technologies are typically applied to treat discharge flows, this type of technology could be used to transform the underground workings into a treatment cell. The reactive treatment media could be added to the mine pool to treat the contained water.	These technologies would may not be effective because the media require some degree of contact to effect treatment and areas within the treatment cell would remain untreated. Also, the bioreactor treatment processes are reversible under certain geologic conditions, and both bioreactors and contact-driven media become expended over time, requiring regeneration.	This technology would be difficult to implement because of the configuration of the workings. Also, the steep surface topography may cause problems with drill rig access, requiring extensive access road construction.	High capital and moderate O&M costs
	Active In-Situ Treatment	Oxygen Addition	Active in-situ treatment may include addition of oxygen to cause iron precipitation within the mine pool. Oxygen addition may be in the form of injection of atmospheric air or ozone, or in the form of chemical oxidants which could be injected.	These technologies would be effective in precipitating iron and other metals. However, the treatment processes are reversible under certain geologic conditions, and the addition of oxygen may cause acidification of the mine pool, requiring further treatment.	This technology would be difficult to implement because of the injection well depths required. Additional material may be required to neutralize pH as iron and other metals precipitate.	Moderate capital and O&M costs

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New Loc ID	Loc Description	Purpose/Rationale	Sampling Method	Depth (ft)	Parameters	Frequency
Soil Screening - Waste Extent Delineation						
Union Mine Area						
T-01	WR pile 7 to east	Surface and subsurface soil samples will be collected to delineate the extend of Site COCs and to provide data for the terrestrial ecological risk assessment. Transects will consist of surface samples or test pits (depending on access to location and presence of sensitive archaeological or structural features) installed to refusal or 20 feet bgs (whichever is shallower). Each transect will start at the waste area edge and continue at 20-foot intervals until waste is no longer observed and XRF copper concentrations are below 500 mg/kg. Step out locations from areas with minimal waste may be sampled with DPT.	TP	0-20'	Field XRF for limited number of metals. Laboratory analysis for TAL metals, ABA, paste pH, CEC, and TOC for three samples from each transect: highest XRF concentrations, clean sample below apparent waste (or deepest sample if waste to bedrock), and surface clean sample at end of transect.	1 per 2-foot interval
T-02	WR pile 7 to south					
T-03	WR pile 3 to southeast					
T-04	WR pile 1 to northeast					
T-05	WR pile 2 to Berm 3					
T-06	WR pile 5 and Berm 5 to southeast					
T-07	northeast of foundations 7-9					
Eureka Mine Area						
T-08	MST pile 3 to northeast	Surface and subsurface soil samples will be collected to delineate the extend of Site COCs and to provide data for the terrestrial ecological risk assessment. Transects will consist of surface samples or test pits (depending on access to location and presence of sensitive archaeological or structural features) installed to refusal or 20 feet bgs (whichever is shallower). Each transect will start at the waste area edge and continue at 20-foot intervals until waste is no longer observed and XRF copper concentrations are below 500 mg/kg. Step out locations from areas with minimal waste may be sampled with DPT.	TP	0-20'	Field XRF for limited number of metals. Laboratory analysis for TAL metals, ABA, paste pH, CEC, and TOC for three samples from each transect: highest XRF concentrations, clean sample below apparent waste (or deepest sample if waste to bedrock), and surface clean sample at end of transect.	1 per 2-foot interval
T-09	BFT pile 2 to northeast					
T-10	BFT pile 1 to southeast					
T-11	Flotation tailings south to road					
T-12	WR pile 11 to north					
T-13	WR pile 20 to south					
T-14	WR pile 15 to northwest					
T-15	WR pile 19 to south					
T-16	area south of WR pile 18					
T-17	WR pile 18 to southwest					
T-18	WR pile 21 to north					
T-19	WR pile 29 to northeast					
T-20	along ridge top					
T-21	WR pile 32 to southwest					
Smith Mine Area						
T-22	Berm 1 to WR pile 38	Surface and subsurface soil samples will be collected to delineate the extend of Site COCs and to provide data for the terrestrial ecological risk assessment. Transects will consist of surface samples or test pits (depending on access to location and presence of sensitive archaeological or structural features) installed to refusal or 20 feet bgs (whichever is shallower). Each transect will start at the waste area edge and continue at 20-foot intervals until waste is no longer observed and XRF copper concentrations are below 500 mg/kg. Step out locations from areas with minimal waste may be sampled with DPT.	TP	0-20'	Field XRF for limited number of metals. Laboratory analysis for TAL metals, ABA, paste pH, CEC, and TOC for three samples from each transect: highest XRF concentrations, clean sample below apparent waste (or deepest sample if waste to bedrock), and surface clean sample at end of transect.	1 per 2-foot interval
T-23	WR pile 38 to east					
Soil Sampling						
Soil Borings						
Union Mine Area						
SB-01	Within WR pile 7 (most downgradient)	Waste area soil samples will be collected from the surficial soil (0-0.5'), subsurface soil (composite from 0.5-10'), and distinct overburden lithologic unit observed within and below each waste pile (unsaturated waste, saturated waste, native below waste, native above bedrock). Soil samples will be collected from borings to delineate the extent of Site COCs and to provide data for the terrestrial BERA and HHRA. Depending on lithologic variability and thickness up to 5 samples per boring may be collected for analysis. The 0-0.5 and <10' depth samples will be used for the HHRA in addition to site characterization.	split spoon/ rotosonic grab/ composite	0'-Top of Bedrock	TAL Metals from all samples. ABA, paste pH, CEC, and TOC from one subsurface sample per boring. SPLP Metals, VOCs, SVOCs, pesticides/PCBs will be sent for 10% of subsurface samples.	up to 5 per boring
MW-01	At bottom of the valley at end of Ephemeral Stream 1					
MW-02	Immediately downgradient of WR pile 7					
MW-03	Immediately downgradient of largest Union Mine WR pile					
MW-05	Top of WR pile 2					
MW-06	Downgradient of WR pile 4					
MW-04	Cross-gradient of WR pile 1					Assess soil upgradient of mine areas. Soil samples will be collected from borings to delineate the extent of Site COCs and to provide data for the terrestrial BERA and HHRA. Subsurface soil samples from areas not expected to contain waste will be collected from the surface soil (0-0.5 feet), surbsurface soil (composite from 0.5-10 feet), and distinct lithologic units observed (unsaturated soil, saturated soil at the center of the well screen if a well is to be installed, and top of bedrock). Up to three samples will be collected for analysis per boring.
MW-07	North of Union Mine by granite quarry and Road 1					
MW-08	Upgradient of WR piles					
MW-09	East of Union Mine Adit	Collect additional surface soil samples to determine waste and native soil characterization.	Grab	0-0.5'	TAL Metals from all samples.	1 per location

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New Loc ID	Loc Description	Purpose/Rationale	Sampling Method	Depth (ft)	Parameters	Frequency						
Soil Sampling (Cont.)												
Eureka Mine Area												
SB-02	WR pile 19	Soil samples will be collected from borings to delineate the extent of Site COCs and to provide data for the terrestrial BERA and HHRA. Waste area soil samples will be collected from the surficial soil (0-0.5'), subsurface soil (composite from 0.5-10'), and distinct overburden lithologic unit observed within and below each waste pile (unsaturated waste, saturated waste, native below waste, native above bedrock). Depending on lithologic variability and thickness approximately 5 samples per boring may be collected for analysis. The 0-0.5 and <10' depth samples will be used for the HHRA in addition to site characterization.	split spoon/ rotosonic grab/ composite	0'-Top of Bedrock	TAL Metals from all samples. ABA, paste pH, CEC, and TOC from one subsurface sample per boring. SPLP Metals (10% of subsurface samples).	up to 5 per boring						
SB-03	WR pile 22											
SB-04	WR pile 29											
MW-10	North of MSP pile 2											
MW-11	Northeast of BFT-2											
MW-13	Downgradient of Eureka WR piles below Eureka Adit											
MW-14	Within Eureka Mine WR pile 15	Soil samples will be collected from borings to delineate the extent of Site COCs and to provide data for the terrestrial BERA and HHRA. Subsurface soil samples from areas not expected to contain waste will be collected from the surface soil (0-0.5 feet), surbsurface soil (composite from 0.5-10 feet), and distinct lithologic units observed (unsaturated soil, saturated soil at the center of the well screen if a well is to be installed, and top of bedrock). Up to three samples will be collected for analysis per boring.				Grab	0-0.5'	TAL Metals from all samples.	Up to 3 per boring			
MW-12	Upgradient of flotation tailings adjacent to mill foundation											
MW-15	Along Road 16, upgradient of middle waste pile area											
MW-16	Road 16 west of WR pile 16											
MW-17	Downgradient of Eureka WR piles 22, 24, and 25											
MW-19	East of the Eureka Mine underground workings											
MW-18	Southeast of the Eureka Mine Adit	Collect additional surface soil samples to determine waste and native soil characterization.	Grab	0-0.5'	TAL Metals from all samples.				1 per location			
MW-20	WR pile 34											
Smith Mine Area												
MW-21	Downgradient of WR pile east of adit.	Subsurface soil samples from areas not expected to contain waste will be collected from the surface soil (0-0.5 feet), surbsurface soil (composite from 0.5-10 feet), and distinct lithologic units observed (unsaturated soil, saturated soil at the center of the well screen if a well is to be installed, and top of bedrock). Up to three samples will be collected for analysis per boring.							split spoon/ rotosonic grab/ composite	0'-Top of Bedrock	TAL Metals from all samples. ABA, paste pH, CEC, and TOC from one subsurface sample per boring. SPLP Metals, VOCs, SVOCs, pesticides/PCBs will be sent for 10% of subsurface samples.	up to 5 per boring
Background												
Soil Background	TBD beyond source areas	Estimate 20 surface and subsurface soil samples from up to 8 borings to be performed in areas that are verified through the XRF screening program to be unimpacted and outside and upgradient or sidegradient to source areas to establish background soil concentrations for site characterization, BERA and HHRA sample data.							macrocore	0-x	TAL Metals, ABA, paste pH, CEC, TOC, SPLP. VOCs, SVOCs, pesticides/PCBs will be sent for 10% of subsurface samples.	20 Samples
Floodplain Soil Sampling												
FP-01 and FP-02	Two Transects across the main on-site tributary stem below Union WR piles	Surface soil samples from floodplain areas to characterize overbank sediments for site characterization and assessing potential terrestrial ecological risk (BERA). Number of samples to be determined by areal extent of sediments observed, estimate up to 6 samples per transect at 0-0.5' depth. Only two locations on-site are currently proposed. Additional off-site locations may be proposed for sampling based on field observations of downstream floodplain areas.				Shovel	0-2'	TAL Metals, ABA, paste pH, CEC, TOC.	Approx.6 samples per location			
Additional Off-Site FP Samples	Additional Transects across PHB at off-site Locs	Surface soil samples from floodplain areas to characterize overbank sediments for site characterization and assessing potential terrestrial ecological risk (BERA). Number of samples to be determined by areal extent of sediments observed, estimate up to 6 samples per transect at 0-0.5' depth. Off-site locations may be proposed for sampling based on field observations of downstream floodplain areas between the site and the PHB Wetland Complex.										

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New Loc ID	Loc Description	Purpose/Rationale	Sampling Method	Depth (ft)	Parameters	Frequency
Monitoring Wells/Groundwater Sampling: A = Shallow OB, B = Deep OB, C = Shallow BR, D = Deep BR						
Union Mine Area						
MW-01B,C	At bottom of the valley at end of Ephemeral Stream 1	Assess overburden and shallow bedrock groundwater conditions at the downgradient boundary of the site. Assess potential contributions from the Foundations areas, Deep bedrock well used to assess potential off-site impacts and to compare with off-site well data.	Low Flow	B: 30-40, C: 50	First Sampling Event: <u>Overburden and bedrock wells:</u> TAL Metals (total and dissolved), total cyanide, sulfate, sulfide, carbonate, bicarbonate, hydroxide, total alkalinity, nitrate, nitrite, total acidity. Field parameters to be collected during sampling: groundwater elevation, pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity. <u>Overburden wells only:</u> VOCs, SVOCs, Pest/PCBs. Second (Confirmation) Sampling Event: <u>Overburden and bedrock wells:</u> TAL Metals (total and dissolved), sulfate, total alkalinity, with additional parameters as needed for wells shown to be impacted during the first sampling event. Field parameters to be collected during sampling: groundwater elevation, pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity.	2 semiannual rounds
MW-02B,D	Immediately downgradient of WR pile 7	Characterize overburden and deep bedrock groundwater downgradient of the lowermost Union Mine pile. Used to compare groundwater and surface water data to evaluate contaminant contribution from site subareas. Deep bedrock well used to assess potential off-site impacts.		B: 30-40, D: 200		
MW-03B,C	Downgradient of Waste Rock Pile 1 and SW-09 at ~ elevation 1,595’.	Critical monitoring location in the valley where tributaries merge to form the main tributary to PHB. Wells will monitor the groundwater contaminant and flow contribution to surface water.		B: 20-30, C: 50		
MW-04B	Upgradient of WR pile 7	Evaluate upgradient contribution to shallow groundwater and surface water		B: 20-30		
MW-05B, C	Top of WR pile 2	Assess saturated thickness of overburden at the largest Union WR pile, upgradient of the largest seep area. Evaluate shallow bedrock impacts.		B: 30-40, C: 50		
MW-06B	Upgradient of Union Mine dam; downgradient of WR pile 2	Assess lateral migration of overburden plume as well as inflow from areas outside the visible waste sources, which have some evidence of mine-related activities. Evaluate groundwater conditions upgradient of the dam.		B: 20-30		
MW-07B,C, D	North and upslope of Union Mine WR piles and underground workings	Assess overburden and bedrock quality upgradient of mine areas.		B:20-30 C: 40 D:100		
MW-08B,C, D	South of Union underground workings, upgradient of WR piles	Monitor water quality in overburden and shallow bedrock in the upper part of the valley to assess potential impacts from the upper Union Mine workings.		B:20-30 C: 40 D:250		
Eureka Mine Area						
MW-09B	Downgradient of flotation tailings pile	Assess overburden water quality impact from tailings pile for correlation with nearby seep data.	Low Flow	B: 20-30	First Sampling Event: <u>Overburden and bedrock wells:</u> TAL Metals (total and dissolved), total cyanide, sulfate, sulfide, carbonate, bicarbonate, hydroxide, total alkalinity, nitrate, nitrite, total acidity. <u>Overburden wells only:</u> VOCs, SVOCs, Pest/PCBs. Field parameters to be collected during sampling: groundwater elevation, pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity. Second (Confirmation) Sampling Event: <u>Overburden and bedrock wells:</u> TAL Metals (total and dissolved), sulfate, total alkalinity, with additional parameters as needed for wells shown to be impacted during the first sampling event. Field parameters to be collected during sampling: groundwater elevation, pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity.	2 semiannual rounds
MW-10B,C	~ 50’ north of southern edge of BFT pile 2 (across access road)	Evaluate impacts of BFT		B: 20-30 C: 40		
MW-11B	Upgradient of flotation tailings adjacent to mill foundation	Assess the saturated thickness and water quality of overburden upgradient of the flotation tailings for comparison with downgradient data. Also to assess the potential impact from fill in the vicinity of the former mill.		B: 20-30		
MW-12B,C,D	Downgradient of Eureka WR piles below Eureka Adit	Characterize overburden and shallow bedrock groundwater downgradient of the northern Eureka Mine WR piles. Used to compare upgradient and downgradient well data to evaluate contaminant contribution from subareas. Deep bedrock well to assess downgradient impact from Eureka mine pool.		B: 20-30, C: 50 D:150		
MW-13B,C	Within Eureka Mine WR pile 15	Assess the saturated thickness in WR/overburden in the WR piles below the Eureka Adit. Assess relationship between surface mine pool and seeps.		B: 20-30, C: 50		
MW-14B,D	Downgradient of Eureka Mine underground workings, upgradient of the former mill.	Characterize overburden groundwater upgradient of the lower Eureka WR and flotation tailings piles, and deep bedrock groundwater downgradient of the mine pool.		B: 20-30, D:220		
MW-15B,C,D	Road 16 west of WR pile 16	Check possible connection between Union and Eureka mines		B: 20-30, C: 50 D:150		
MW-16B,C,D	Downgradient of Eureka WR piles 22, 24, and 25	Characterize overburden and bedrock groundwater downgradient of the middle Eureka WR piles and the Eureka Mine pool.		B: 10-20, C: 40 D:220		
MW-17B	East of the Eureka Mine underground workings	Assess shallow groundwater quality downgradient of the Upper Cut area.		B: 20-30		
MW-18D	Along watershed divide near peak of Pike Hill	Deep bedrock well used to assess potential impact of Eureka Mine pool.		D:100		

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New Loc ID	Loc Description	Purpose/Rationale	Sampling Method	Depth (ft)	Parameters	Frequency
Monitoring Wells/Groundwater Sampling: A = Shallow OB, B = Deep OB, C = Shallow BR, D = Deep BR (Cont.)						
Smith Mine Area						
MW-19B,C,D	downgradient of WR pile east of adit.	Assess overburden and bedrock groundwater conditions downgradient of the mine.	Low Flow	B:10-20, C: 30 D: 75	First Sampling Event: <u>Overburden and bedrock wells:</u> TAL Metals (total and dissolved), total cyanide, sulfate, sulfide, carbonate, bicarbonate, hydroxide, total alkalinity, nitrate, nitrite, total acidity. Field parameters to be collected during sampling: groundwater elevation, pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity. <u>Overburden wells only:</u> VOCs, SVOCs, Pest/PCBs. Second (Confirmation) Sampling Event: <u>Overburden and bedrock wells:</u> TAL Metals (total and dissolved), sulfate, total alkalinity, with additional parameters as needed for wells shown to be impacted during the first sampling event. Field parameters to be collected during sampling: groundwater elevation, pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity.	2 semiannual rounds
Mine Pool Boreholes						
MW-20D	East of Union Mine Adit	Bedrock well to penetrate the Union Mine pool in a flooded portion of the mine to assess mine pool water quality.	Grab	D: 220	First Sampling Event: <u>Overburden and bedrock wells:</u> TAL Metals (total and dissolved), total cyanide, sulfate, sulfide, carbonate, bicarbonate, hydroxide, total alkalinity, nitrate, nitrite, total acidity. Field parameters to be collected during sampling: groundwater elevation, pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity. <u>Overburden wells only:</u> VOCs, SVOCs, Pest/PCBs. Second (Confirmation) Sampling Event: <u>Overburden and bedrock wells:</u> TAL Metals (total and dissolved), sulfate, total alkalinity, with additional parameters as needed for wells shown to be impacted during the first sampling event.	2 semiannual rounds
MW-21D	Southeast of the Eureka Mine Adit	Bedrock well to penetrate the Eureka Mine pool in a flooded portion of the mine to assess mine pool water quality.		D: 80	Field parameters to be collected during sampling: groundwater elevation, pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity.	
Shallow Wells - TBD						
MW-XXA	up to 8 shallow overburden wells at other proposed RI well clusters TBD during drilling.	Assess the potential for, and conditions within, any differentiated overburden aquifers (e.g. shallow sand versus deeper basal till, or perched groundwater above a lower water table) that are observed during the installation of the proposed RI wells (ie. the -B, -C, and -D series wells). At these locations, install a well screened above a well with a 10-foot screen set at the top of bedrock	Low Flow	A: 5-15	First Sampling Event: <u>Overburden and bedrock wells:</u> TAL Metals (total and dissolved), total cyanide, sulfate, sulfide, carbonate, bicarbonate, hydroxide, total alkalinity, nitrate, nitrite, total acidity. Field parameters to be collected during sampling: groundwater elevation, pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity. <u>Overburden wells only:</u> VOCs, SVOCs, Pest/PCBs. Second (Confirmation) Sampling Event: <u>Overburden and bedrock wells:</u> TAL Metals (total and dissolved), sulfate, total alkalinity, with additional parameters as needed for wells shown to be impacted during the first sampling event. Field parameters to be collected during sampling: groundwater elevation, pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity.	2 semiannual rounds
Residential Drinking Water						
Residential Drinking Water	Estimated 30 residences in the vicinity of the source areas	Locations TBD within approximately one mile of on-site sources. Note: only six private water supply wells listed with VTDEC within a 1-mile radius	Grab	TBD	TAL Metals (total and dissolved), total cyanide, sulfate, and sulfide.	2 semiannual rounds

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New Loc ID	Loc Description	Purpose/Rationale	Sampling Method	Depth (ft)	Parameters	Frequency
Surface Water Sampling						
SW-01	Start of ES 2	Stream not directly draining from WR - impact unknown	Dipper-Grab	NA	TAL Metals (total and dissolved), total cyanide, sulfate, total alkalinity, carbonate, bicarbonate, hydroxide, sulfate, sulfide, nitrate, nitrite, total acidity, TSS, TDS. Field parameters to be collected during sampling: pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity.	2 semiannual rounds
SW-02	End of ES 2 above USGS weir	Estimate contaminant load from streams not directly draining from WR				
SW-03	start of ES 3	Stream not directly draining from WR - impact unknown				
SW-04	End of ES 3	Stream not directly draining from WR - impact unknown				
SW-05	End of ES 1 above junction with stream to south	Estimate contaminant load from streams not directly draining from WR				
SW-06	end of stream south of ES 1	Evaluate potential primary impacted stream from source area				
SW-07	downstream of south of ES-1 and stream to south junction					
SW-08	Stream below USGS weir	Evaluate primary drainage off-site				
SW-09	end of ES 8 below foundations 4 and 5	Evaluate surface water impacts downstream of (but not close to) WR piles				
SW-10	Start of ES 1	Stream does not appear to directly drain from WR - impact unknown				
SW-11	Seep east of WR pile 1 and 3					
SW-12	Seep northeast of WR pile 1					
SW-13	End of ES 4 above ES 6 confluence	Evaluate WR pile influence on ES 4				
SW-14	Start of ES 4 below dam	Uppermost surface water downhill of Union shafts/adits and upper workings				
SW-15	ES 6 above stream\ confluence above WR pile 3	Evaluate impacts just above lower large WR pile area and streamload to major drainage				
SW-16	Just above onfluence of SW-15 stream with ES 6	Evaluate downstream BFT pile impacts				
SW-17	Start of unnamed stream east of ES 6	Evaluate BFT pile impacts				
SW-18	downstream of confluence of ES 6 and stream to east					
SW-19	ES 6 below MSP piles	Evaluate MSP impacts				
SW-20	Start of ES 6 above Road 2	Evaluate WR pile impact north of Eureka mine				
SW-21	Cookville Brook at about 1475' contour	Stream downgradient of expected Smith mine drainage				
SW-22	Cookville Brook at about 1500' contour	Stream downgradient of expected Smith mine drainage				
SW-23	Cookville Brook at about 1550' contour	Stream upgradient of expected Smith mine drainage				
SW-24	Union Mine Adit portal	Potential mine pool sample; compare with previous				
SW-25	Union Mine Shaft trench	Mine pool sample; compare with previous				
SW-26	Open Cut 4 (Union mine)	Highest pooled water sample associated with Union mine - may represent drainage to mine				
SW-27	Eureka Lower Adit portal	Potential drainage to mine pool				
SW-28	Eureka Lower Shaft portal	Potential mine pool sample; compare with previous				
SW-29	Smith shaft portal	Potential mine pool sample; compare with previous				
SW-XX	up to 4 locations TBD based on available surface water	Identify additional pooled/flowing areas for hydro/chemical evaluation based on site visit during high-water period.				
Off-Site Surface Water Sampling						
SW-30 through 37	Cookville Brook (including tributaries)	Stream downgradient of expected Smith mine drainage. Additional surface water samples for confirmation of nature and extent and correlection with other RI data.	Dipper-Grab	NA	TAL Metals (total and dissolved), total cyanide, sulfate, total alkalinity, carbonate, bicarbonate, hydroxide, sulfate, sulfide, nitrate, nitrite, total acidity, TSS, TDS. Field parameters to be collected during sampling: pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity.	One per location
SW-38	Pike Hill Brook	Stream upgradient of expected Union/Eureka mine drainage. Background surface water sample and correlation with other RI data.				
SW-39 through 42	Pike Hill Brook	Stream downgradient of expected Union/Eureka mine drainage. Additional surface water samples for confirmation of nature and extend and correlection with other RI data.				

Table 9-1
Field Investigation Sampling Summary
Pike Hill Copper Mine Superfund Site
Corinth, Vermont
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New Loc ID	Loc Description	Purpose/Rationale	Sampling Method	Depth (ft)	Parameters	Frequency
Vernal Pools						
Vernal Pools	TBD	In early spring (late April/early May), a vernal pool presence evaluation will be conducted. All isolated depressional wetlands with no permanent inlet or outlet will be identified and mapped. All mapped pools will be visited a second time (approx. 4-6 weeks later) to determine if vernal pool characteristics as defined by Vermont DEC are present. Surface water samples will be collected from each positively identified vernal pool and a qualitative assessment of pool conditions will be determined using VTDEC guidelines (VTDEC 2003).	Dipper-Grab	NA	TAL Metals (total and dissolved), total cyanide, sulfate, total alkalinity, carbonate, bicarbonate, hydroxide, sulfate, sulfide, nitrate, nitrite, total acidity, TSS, TDS. Field parameters to be collected during sampling: pH, temperature, conductivity, dissolved oxygen, ORP, and turbidity.	One per location
On-Site Sediment Sampling						
SD-01 through SD-20	Eureka/Union Mines	Shallow sediment samples colocated with surface water samples (SW-01 through SW-20) from defined channels below seeps and within tributary stem to evaluate whether sediment should be considered a waste source material.	Bucket auger, shovel or tube sampler	0-2'	TAL Metals on all samples. ABA, Paste pH, SPLP Metals on 10% of samples.	One per location
SD-21 through SD-23	Smith Mine Area	Shallow sediment samples colocated with surface water samples (SW-21 through SW-23) from defined channels below seeps and within tributary stem to evaluate whether sediment should be considered a waste source material.				
Off-Site Sediment Sampling						
SD-30 through SD-37	Cookville Brook (including tributaries), co-located with SW-30 through SW-37.	Stream locations downgradient of expected Smith mine drainage. Additional sediment samples estimated for HHRA.	Bucket auger, shovel or tube sampler	0-0.5'	TAL Metals on all samples. ABA, Paste pH, SPLP Metals on 10% of samples.	One per location
SD-38	Pike Hill Brook	Stream location upgradient of expected Union/Eureka mine drainage. Background sediment sample and correlation with other RI data.				
SD-39 through SD-42	Pike Hill Brook	Stream locations downgradient of expected Union/Eureka mine drainage. Additional sediment samples for confirmation of nature and extend and correlection with other RI data.				
Other HHRA Sampling						
Fish Sampling	None	No additional fish sampling is anticipated as existing fish sampling data is assumed to be sufficient to support HHRA	NA	NA	NA	NA
Earthworm/Plant Tissue/Small Mammal BERA Sampling						
Soil Invertebrates	Downgradient from: Eureka Mine waste piles, Eureka Mine tailing piles, Union Mine waste piles, Smith Mine waste piles	Where habitat conditions are suitable, earthworm samples will be collected and submitted for subsequent contaminant analysis. A minimum of 20 composite invertebrate samples will be collected downgradient of the 4 EAs. Background: 5-10 background earthworm samples will be colocated with background soil samples.	Shovel	0-12cm/5"	TAL metals (all samples) and percent lipid (50%)	25-40 samples incl. bkg
Small Mammals	Downgradient from: Eureka Mine waste piles, Eureka Mine tailing piles, Union Mine waste piles, Smith Mine waste piles	Where habitat conditions are suitable, small mammal whole-body will be collected for subsequent contaminant analysis. A minimum of 20-30 individual samples will be collected (5 per waste or tailings pile area). Background: Data collected from Ely Copper Mine small mammal background samples will be used as an appropriate analog.	TBD	NA		

Notes: WR = Waste Rock, BFT = Burnt Flotation Tailings, MSW = Magnetic Separation Waste, PHB = Pike Hill Brook, ES = Ephemeral Stream

APPENDIX A

FAILURE MODES AND EFFECTS ANALYSIS



Failure Modes and Effects Analysis at Pike Hill Copper Mines Superfund Site

SLR Ref: 117.00975.00003

August 2019



Failure Modes and Effects Analysis at Pike Hill Copper Mines Superfund Site

Prepared for:

Nobis Engineering, Inc.

18 Chenell Drive
Concord, NH 03301

This document has been prepared by SLR International Corporation. The material and data in this technical report were prepared under the supervision and direction of the undersigned.

A handwritten signature in blue ink, appearing to read "Tarik Hadj-Hamou", written over a horizontal line.

Tarik Hadj-Hamou, Ph.D., P.E. (California)
Principal

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APPENDICES

Appendix A	Technical Memorandum from Charles Mettler about Pike Hill Mines Geology
Appendix B	Pike Hill Mines FMEA Calculations

ACRONYMS

%	Percent
AMSL	Above Mean Sea Level
bgs	Below Ground Surface
BMP	Best Management Practice
FMEA	Failure Modes and Effects Analysis
FS	Feasibility Study
ft	Feet
ft ³ /sec	Feet Cubed Per Second
gpm	Gallons Per Minute
IDF	Intensity Distribution Function
MIW	Mining Influenced Water
MMI	Modified Mercalli Intensity
NRC	National Resources Conservation
OU	Operable Unit
pcf	Pounds Per Cubic Foot
PGA	Peak Ground Acceleration
PHM	Pike Hill Mines
ROD	Record of Decision
RI	Remedial Investigation
RPN	Risk Priority Number
SLR	SLR International Corporation
USEPA	United States Environmental Protection Agency
USGS	US Geological Survey

1. INTRODUCTION

1.1 TERMS OF REFERENCE

This Technical Report presents the Failure Mode and Effects Analysis (FMEA) conducted at the three mines located in Corinth Vermont: Eureka, Union, and Smith mine collectively referred to as the Pike Hill Copper Mines Superfund Site (Pike Hill Mines) by SLR International Corporation (SLR). The FMEA reported in this Technical Report is focused on the underground workings (adits, shafts, stopes, etc.) of the Pike Hill Mines and impacts from potential releases of mining influenced water (MIW) from these underground workings. This FMEA was developed for the Nobis Group (Nobis) in support of a Remedial Investigation and Feasibility Study (RI/FS) currently being conducted by the U. S. Environmental Protection Agency (USEPA). The FMEA scope was limited to identifying the potential failure modes that could result from planned or proposed regulatory activities to be undertaken by the USEPA at the Pike Hill Mines and what failure modes may remain unresolved as a result of the planned or proposed remedial actions. While this FMEA does discuss mitigation and contingency measures, the assumption is that activity-specific FMEAs will be developed in support of the RI/FS efforts for each of the three mines and that the selection and more rigorous evaluation of these measures would be conducted at that time.

The FMEA was performed at the request of Mr. Andy Boeckeler of Nobis Engineering Inc. (Nobis) under subcontract 16-NH80111-003 between SLR and Nobis.

The FMEA and this Technical Report were prepared by Dr. Tarik Hadj-Hamou of SLR and Mr. Ryan Dougherty formerly of SLR and reviewed by Dr. Ian Hutchison, also of SLR.

1.2 FMEA TEAM

The FMEA was performed under the direction of Dr. Ian Hutchison of SLR. The following technical staff participated in the FMEA and the preparation of the Technical Report:

- Dr. Ian Hutchison (SLR) – A civil engineer with 40 years of experience in mining engineering and experience in risk analysis and the performance of FMEA.
- Dr. Tarik Hadj-Hamou (SLR) – A civil engineer with over 35 years of experience in geotechnical engineering including stability analysis of earth structures (tunnels, slopes) and experience in probabilistic, hazard, and risk analysis.
- Mr. Ryan Dougherty (formerly of SLR) – A project engineer with three years of mining engineering experience.
- Mr. Charles Mettler (SLR) – A structural geologist with over 28 years of experience, including 20 years in the mineral resource industry, responsible for the design and execution of national and international mineral exploration programs.
- Mr. Andy Boeckeler (Nobis) – Project manager with over 25 years of experience, including over 15 years investigating abandoned mine sites, who managed and oversaw the preparation of the Draft Conceptual Site Model Technical Memorandum for Pike Hill Mines (Nobis, 2008).

- Mr. Brett Kay (Nobis) – Civil Engineer with over 12 years of experience, including over 8 years performing mine site remedial actions, familiar with the investigation activities to be carried out at Pike Hill Mines.
- Mr. Matt Kierstead (Milestone Heritage Consulting) – A mine historian with over 25 years of experience and a deep knowledge of the conditions at Pike Hill Mines and was involved in the writing of the report Historic/Archaeological Mapping and Testing, Pike Hill Mines Sites by PAL (2011).

A working FMEA session was held at the Pike Hill Mines during a site visit and inspection conducted on November 15, 2016. This working session was attended by Mr. Brett Kay and Andy Boeckeler of Nobis, Dr. Tarik Hadj-Hamou of SLR, Mr. Ed Hathaway of the USEPA Region 1, Linda Elliott of the State of Vermont, and Mr. Matt Kierstead of Milestone Heritage Consulting.

During the working session and the site visit, the overall purpose of the FMEA was established and the impacts that needed to be considered were discussed—namely, impacts that may result from a sudden and uncontrolled release from the Eureka and Union mine pools.

Preparation of the FMEA involved meetings and conference calls with the technical staff listed previously in this section.

2. PURPOSE

The USEPA has requested the performance of the FMEA of the underground workings at the Pike Hill Mines with a focus on the risks and impacts associated with the potential release of MIW.

The FMEA identifies potential failure modes associated with the underground workings and considers triggering events such as earthquakes, extreme weather, and disturbances induced during the performance of site investigations such as heavy drilling, test-pit excavations, and other explorations of underground features (portals, adits, shafts).

The purpose of the FMEA is to provide the USEPA, contractors, and other agencies working on or performing oversight for the RI/FS for Pike Hill Mines, with an appreciation of the risks and impacts associated with identified failure modes at each stage of the RI/FS process. This FMEA was not developed to select or provide the rigorous evaluation of the mitigation, contingency, and planning measures that may be required to address the identified failure modes.

3. BACKGROUND

3.1 PIKE HILL MINES

3.1.1 PIKE HILL

Pike Hill in Corinth, VT was one of three historic copper mine sites that operated in the 20-mile-long Orange County, VT, “Copper Belt” mining district during the nineteenth and twentieth centuries. The approximately 200-acre Pike Hill site lies within the watersheds of Cookeville Brook and Pike Hill Brook—tributaries to the Waits River, which flows into the Connecticut River. From south to north, three mines were opened and exploited: the relatively small Smith Mine about 0.4 miles south of the top of Pike Hill, and the larger Eureka Mine and Union Mine which lie several hundred feet apart and extend north of the summit. These three physically separate iron-copper sulfide orebodies were mined intermittently between 1846 and 1919. The greatest periods of production were during the Civil War, then between 1878 and 1881 when the ore was sent to the Ely Mine’s smelter, and again during World War I when ore was concentrated on site in a flotation mill. Pike Hill Mines produced approximately 4,300 tons of copper, or about 6 percent of total “Copper Belt” production based on known figures, a distant third compared to the much larger Ely and Elizabeth Mines to the south (PAL 2011). During World War II the U.S. Bureau of Mines (USBM) conducted investigations, documenting the known extent of underground workings and interpreting the nature and extent of the ore body (White and Eric 1944). Over time, the Pike Hill Mines adits and shafts have been labelled inconsistently between documents. Table 3.1 summarizes the names used over time and in previous studies as well as the status of the underground openings. The second column presents the naming convention that will be used in the FMEA. Through their historical research and archaeological survey, PAL, Inc. developed this naming convention that is used herein. A complete and detailed description of the underground workings, their history, and estimated dimensions, as well as a detailed description of other features at Pike Hill are provided in the PAL archaeological report (PAL 2011). The plan view and cross sections of the underground workings currently used with the PAL naming convention for Smith Mine, Eureka Mine, and Union Mine are shown on Figures 3-1 through 3-6.

3.1.2 SMITH MINE

Copper ore was discovered at the Smith Mine in 1845, and two Worcester, MA men mined a small amount of ore they shipped to Boston for smelting in 1846. In 1907, E.L. Smith reopened the mine, reportedly developing a 150-ft tunnel and 40-ft crosscut. Smith shipped some ore in 1908, but the mine was dormant in 1909. Smith worked the mine again in 1913 and then abandoned it, leaving a relatively small area of waste rock piles, the open Smith Shaft, and the Smith Adit, now partially collapsed (PAL 2011). In 1944 the workings reportedly consisted of a 70 ft deep inclined stope (Smith Shaft) connected to the surface by the 50 ft long Smith Adit, with an irregular opening in the back of the stope. At the north end close to the ore outcrop was a 40-ft drift and a flooded winze sunk about 40 feet down the dip of the vein below the stope north of the Smith Adit (White and Eric 1944).

3.1.3 EUREKA MINE

Copper mining at the Eureka Mine began in 1853 when ore was extracted from the “Cuprum” open cut near the top of the hill and shipped to offsite smelters. High Civil War copper prices prompted underground operations in 1863. The Corinth Copper Company excavated the Cuprum Shaft, drove the 112 ft long Upper Adit in the Cuprum ore lens and shipped ore to Baltimore for smelting. When the Cuprum Shaft was 400 ft deep, the company drove the 500 ft long Lower Adit to intercept it but missed, instead striking a new, lower ore lens coined “Eureka.” When the mine first closed in 1868, the Upper Adit reportedly caved in. The Pike Hill Mines Company briefly reopened the mine from 1905 to 1907. They connected the Cuprum and Eureka ore lenses, and drove an underground shaft to reach a new, third, high-grade ore lens. They installed gasoline-powered hoists in the Cuprum and Eureka shafts, and processed the ore with magnetic separation equipment. Rising World War I copper prices prompted resumption of mining in 1916. The Pike Hill Mines Company installed a 100 tons per day (tpd) flotation mill and produced 824,000 lbs of copper before the mine closed for the last time in 1919. The Eureka Mine underground workings occupy an area approximately 200 feet wide by approximately 600 feet long, sloping downward to the northeast from the old Cuprum Mine at the peak of Pike Hill along the 25 to 30-degree dip of the ore body. Descriptions of the Eureka Mine underground workings during later operations conflict, possibly reflecting rapid mining from the irregular orebody. However, the existence of four mine openings are understood for the mine: the open Cuprum Shaft, collapsed Upper Adit, open Eureka Shaft, and open Eureka Adit, which was the main haulage adit for the life of the mine after 1905 (PAL 2011, White and Eric 1944).

3.1.4 UNION MINE

Surface mining at the Union Mine site began in 1854, likely at the now mined-out outcrop immediately south of the Union Shaft. Underground operations began in 1863, driven by high Civil War copper prices. The Union Copper Mining Company reportedly worked the mine from two short adits on the ore bed and planned a 665-ft long deep adit to develop more. The shorter of these two adits may have been the outcrop excavation or the 100 ft long open cut visible today east of the Union Shaft. The other, approximately 300 ft long Main Adit is now partially collapsed. It appears unlikely that the 665 ft long deep adit was ever developed, due to lack of surface evidence, and water being retained in the mine today rising to the level of the Union Adit. The Union Mine shipped ore averaging 8 to 10 percent copper to Baltimore smelters between 1865 and 1877 when it closed in the wake of the economic Panic of 1873. In 1878 the Vermont Copper Mining Company purchased the Union Mine, reopened it and shipped the ore nine miles south to the Ely Mine smelter. Miners accessed the underground workings via the inclined 900-foot-deep Union Shaft, reaching 766 ft below the Union Adit level. The mine worked four overlapping ore lenses down to a depth of 300 feet. The Union Shaft left the ore 500 feet below the Union Adit level, and continued down in the hanging wall. The lower ore bodies were developed by winzes sunk in the shaft footwall. The Union Mine orebody was exhausted in 1881, and the mine was abandoned in 1882. The Union Mine reportedly produced 31,405 tons of ore between 1866 and 1881 (PAL 2011, White and Eric, 1944).

3.2 FAILURE MODES AND EFFECTS ANALYSIS

FMEA is a systematic methodology to quantify the risk associated with each failure mode of components of engineered systems. A FMEA combines each failure mode, its cause, the effects of that failure, and the impact of corrective or mitigating actions applied to that failure mode.

By casting the FMEA in a probabilistic framework through the likelihood of occurrence (probability of occurrence) of each failure mode and a measure, of the severity of the consequence (the effect) of each failure mode, the risk associated with each failure mode can be evaluated and the failure modes ranked. To facilitate analyses and quantification of risk, numeric scales are developed as a measure of the likelihood of occurrence and the severity of the failure mode.

The ranking is based on the Risk Priority Number (RPN) which is the product of two numbers: the measure of likelihood and the measure of severity. An RPN is calculated for each failure mode identified which allows ranking from highest risk to lowest risk. Where the highest RPN represents the highest risk at the site under consideration.

Consequently the steps in a FMEA are:

- Identifying all possible failure modes. The list should be exhaustive and include all possible failure modes. Those perceived as not likely to occur or with negligible consequence can be eliminated from further consideration at that stage. For those remaining failure modes, the FMEA process will — through the association of likelihood of occurrence and measure of severity and the RPN — quantify the risk associated with all the failure modes and therefore allow for elimination of those that are considered insignificant.
- Developing the probability of occurrence of each failure mode and the associated likelihood measurement scale. The scale of likelihood can be quantitatively developed based on numbers or statistics, or qualitatively developed based on interpretation and engineering judgement.
- Developing a scale for severity of the consequences associated with each failure mode. The scale for severity can also be based on qualitative assessment (e.g. level of erosion, societal perception, etc.) or on quantitative assessment or metric (e.g. cost to repair).

It is fairly common to assemble a team to identify the failure modes of an engineered system and develop likelihood and severity scales. The purpose of assembling a team is to include experts or personnel that are familiar with the engineering system, its possible failure modes, and associated consequences, in order to accurately assign probabilities of occurrence and severity ratings.

In addition to a table ranking of the failure modes based on their RPN, another convenient representation of the results of the FMEA is a color coded matrix, known as the risk characterization matrix. An example of such would include likelihood of occurrence as the column heading and consequence severity as the row heading. Each failure mode will then be placed in the cell formed by the intersection of the severity of the consequence and the likelihood of occurrence of that failure mode.

A benefit of the FMEA is the assessment of the effectiveness of mitigation, corrective, or remedial actions for each failure mode by reevaluating the probability of occurrence of the mitigated failure mode and the severity of its mitigated consequence. The RPN of the mitigated failure mode is calculated and compared to that of the unmitigated failure mode. Multiple mitigative or corrective actions can be compared by evaluating mitigated RPNs to identify the most efficient action.

It is noteworthy that the RPN can be reduced by lowering either the likelihood of occurrence, the severity of the consequences, or both. For a natural system, the corrective actions tend to address severity rather than the likelihood of occurrence that may be related to external conditions or natural hazards not under operator control (e.g. landslides, earthquake, rock falls, etc.).

Once the information is generated, the calculations are conducted and the FMEA process lends itself to a systematic spreadsheet approach.

4. FRAMEWORK OF FMEA

4.1 GENERAL CONDITIONS

As described in Section 3.1, the Pike Hill Mines are a combination of open cut and underground workings. Shafts, adits, winzes, and stopes were excavated as documented by USGS (White and Eric, 1944), PAL (2011), and Nobis (2017a). A plan view of the underground workings at each of the three mines is shown on Figures 3-1 through 3-3 and cross sections of each network of underground working on Figures 3-4 through 3-6. These figures were obtained and adapted from Nobis (2017b). These figures list the adits and shafts that have been identified, as well as the current (August 2019) understanding of their conditions.

4.2 LIKELIHOOD SCALE

The likelihood scale was established qualitatively following discussions within the FMEA team and the USEPA and a review of the FMEA performed at the Leadville Mine drainage tunnel (BUREC, 2008) and the experience gained by performing the FMEAs at the Elizabeth and Ely Mines (SL 2016a, 2016b) using these four classes. Four classes of likelihood have been retained:

- Ruled out or Highly Unlikely;
- Low or Unlikely;
- Moderate or Neutral; and
- High or Likely.

Each class is described in detail in Table 4-1 along with an assigned probability of occurrence and likelihood numeric scale. The likelihood and associated probability of occurrence cover the time period considered. Typically, all things being equal, the probability of a failure mode will tend to be equal or higher for a given event if the exposure period is longer. Time periods specific to Pike Hill Mines for this FMEA are discussed in Section 4.5.

4.3 CONSEQUENCE SCALE

The consequence scale is established as a site-specific scale based on the potential impact from a failure. At the Pike Hill Mines the main potential impacts are related to a large release of MIW and are:

- Economic impact to the downstream population such as loss of roads or access to the property;
- Impact on water quality within the site or outside the site within the Waits watershed (i.e. Pike Hill Brook) due to elevated iron, aluminum, copper, and zinc from a MIW release from any adit or shaft along with the associated impacts from any suspended sediment and waste rock transported along with the release;

- Impact on water quality and visual aesthetics of downstream surface water through erosion and sediment discharge due to scouring of unconsolidated soil, waste rock, and tailings that may occur as a large release of MIW; and
- Impacts on site workers or hikers visiting the area near an adit or portal during a release.

Four levels of severity have been identified ranging from level 0 (no significant consequences) to level 3 (maximum impact). These four levels are listed in Table 4-2 with a description of the impact associated and a severity scale for use in the calculation of the RPN.

It is noted that, in addition to the consequences described above, changes to the physical structure, air flow, temperature regime, and/or moisture or standing water conditions may occur within the underground workings as a result of an adit, shaft, or stope collapse. These changes could result in impacts to threatened or endangered species of bats that hibernate within or otherwise occupy the underground workings.

4.4 RISK CHARACTERIZATION MATRIX

The risk characterization matrix is obtained by combining the likelihood and the consequence numeric scales. The risk characterization matrix for the Pike Hill Mines underground workings is shown on Figure 4-1. It is a 4 x 4 matrix where the four columns are the four levels of likelihood and the four rows are the four levels of consequence.

One such matrix was developed for each of the three networks of underground workings (i.e. Smith Hill, Union Mine, and Pike Hill Mines). Each of the potential failure modes and their associated consequence are assigned the appropriate cell based on likelihood and severity measures.

4.5 ASSUMPTIONS

In performing the FMEA for the underground workings at Pike Hill Mines, the following assumptions were made:

- This FMEA is focused solely on failure modes that would lead to the release of MIW from the underground workings at any of the three mines, which could subsequently impact the environment, the aesthetics of the site post-closure, the community, and/or pose health and safety risks to humans.
- A failure is defined in this FMEA as an uncontrolled release of MIW. Two types of failure can occur:
 - a. Catastrophic failure associated with the sudden release of MIW if a blockage in an adit abruptly fails (blow-out).
 - b. Limited failure impact when, because of changes in configuration (new blockage, higher flows, etc.), the low flows currently observed are transferred to a higher elevation adit or shaft but the discharge is similar to previous recordings.
- MIW seepage from the underground working has been observed over time at the Union Adit and Eureka Lower Adit. However regular monitoring or measurement of seepage at these locations had not been conducted as of August 2019.

- In the absence of measured MIW discharge rates at Pike Hill Mines, the measured discharge rates from the nearby Elizabeth and Ely Mines were used to estimate the filling rates of the underground workings in the event of a blockage. This assumption is deemed reasonable based on the generally similar geology of the three sites.
- The available information about the dimensions of the underground workings (adits, shafts, stopes, and cavern voids) was used to determine maximum volumes of water that could be released during a failure. The data and volumes are listed in Table 4-3. The filling rate of these underground workings was calculated using the filling rates reported in Table 4-3. To be conservative with respect to the potential release volumes, the FMEA assumed that each mine feature could be blocked near its entrance resulting in the maximum potential release of MIW. While this is likely the existing condition for most of the underground workings, it is possible that a blockage could occur further inside the underground mine feature (shafts and adit) or in multiple locations. These additional permutations were not considered since the goal of this FMEA was to identify the potential failure modes and provide general information to support mitigation and planning with the expectation that the remedial design would address the worst-case scenario. It is also expected that for future phases of work (e.g. remedial design or remedial action), activity-specific FMEAs would be developed to provide greater detail with respect to mitigation and contingency measures that would be applicable to those specific activities.
- The three mines forming the Pike Hill Mines (Smith, Union, and Eureka) are not connected (based on information obtained as of March 2018).
- While it is theoretically possible that simultaneous releases of MIW from mine features could occur, this scenario was not evaluated in the FMEA. If remedial action is not implemented in the short-term, it may be appropriate for long-term contingency and monitoring plans to consider the potential for a simultaneous release from mine features in a similar time frame.
- The FMEA considers only one phase of activity at the Pike Hill Mines. This phase is labeled Current Conditions and Investigation and covers the period during which investigation is completed and is assumed to be up to 5 years in duration. Such investigation may include geotechnical investigation drilling into the adits from above and removal of the collapsed materials at the portals.

5. FAILURE MODES

5.1 DEFINITIONS

The failure modes considered are those resulting in the uncontrolled release of MIW to the environment substantially in excess of any seepage or discharge rates currently released from the underground workings of the Pike Hill Mines. As discussed in Section 5.4, these flows could increase slightly following a winter characterized by a thick snow cover (e.g. in excess of 800 mm) but it is believed that flows would remain within the same order of magnitude (i.e. not experience a 10-fold increase).

For an uncontrolled release from an adit to occur, the following succession of events needs to happen:

1. The adit is blocked.
2. Water accumulates behind the blockage.
3. The blockage ruptures either suddenly (catastrophic release) or is gradually eroded and fails partially or totally (slow to fast release) as a result of natural or man-made influences.

Causes for a blockage to occur in an adit include:

- Collapse of the adit due to the geological nature of the rock formation;
- Collapse of the adit induced by outside events such as earthquakes or extreme weather;
- Collapse of the adit induced by construction or investigation activities (weight of equipment, ground vibrations, and/or stress relief from unloading the overburden (soil, rocks, waste rock, or other materials); or
- Collapse of the roof or walls of the adit induced by investigation activities such as drilling.

The likelihood of each cause of blockage at Pike Hill Mines is discussed in the following sections of this Technical Report.

Because of the lack of site-specific data and a relatively comparable geology, geomorphology, and structure, it is assumed that the water will percolate through the rock formation, accumulate behind blockages, and fill the adits at a rate commensurate with the rates observed and recorded at the nearby Elizabeth and Ely Mines (Nobis 2015) and reported in Table 4-3. These rates may rise slightly if affected by rain and/or snow. Effects of rain and/or snow on infiltration into the mine, and on flows out of the adits, are discussed in Section 5.3.3 and 5.3.4 of this Technical Report.

Rupture of a blockage will occur if:

- The pressure behind the blockage is greater than the internal shear strength of the blockage or greater than the frictional force developed between the blockage and the roof, floor, and walls of the adit;
- The blockage erodes away due to soil saturation and/or piping; or

- Some activity reduces the resisting force, such as removal of the material within the blockage (e.g. removal of sloughed materials at the portals) waste rock excavation.
- Exploratory investigations destabilize the blockage.

In addition to the failure modes related to the failure of an existing blockage at an adit, failure modes specific to exploration and construction activities are discussed in Section 5.3.2.

5.2 GEOLOGICAL CONSIDERATION

Two types of blockages are related to the geological weathering and degradation of the rock formation in which the underground workings of Pike Hill Mines are located. The first type is the sudden collapse of the adit or other underground structures (stopes, shaft), and the second type is more time dependent and is related to weathering and deterioration. Only the first mechanism (sudden collapse) was evaluated as a potential cause of a partial or full blockage for the focus period of this FMEA (0-5 year period).

A review of the geology of the Pike Hill Mines and available information was performed by Mr. Charles Mettler, a geologist specialized in working in stratified underground ore deposits. Upon reviewing the available geological information, including the 2008 URS geotechnical investigations performed at the nearby Elizabeth and Ely Copper Mines, Mr. Mettler determined that the carbonate-based lithologies found at Pike Hill are far more susceptible to corrosion and degradation when exposed to low-pH waters than other deposits of the Vermont Copper Belt. The sulfide ore zones at Pike Hill are presumed to be highly foliated and sheared with minor faults parallel to the foliation, with shearing being the main structural mechanism for collapse of the underground workings. He also concluded that the probability of collapse of the underground workings would increase closer to the surface due to a combination of factors such as a low stress environment, increased fracture frequency, and decrease in the shear strength of the encompassing material.

Mr. Mettler concluded that both the likelihood of a blockage due to collapse of an adit, and of blockage due to weathering of rock, were high but would be time dependent and more likely to occur in the long term as a result of geochemical alteration of the encompassing material. He also concluded that the activities of this FMEA's focus (investigative and remedial activities) posed a moderate to high risk of collapse of the underground workings.

Consequently:

- The risk of an uninduced collapse of the underground workings resulting in a full blockage within the five year FMEA timeframe is considered to be low.
- The risk of an induced collapse (i.e. caused by investigative or remedial activities) of the underground workings resulting in a full blockage within the five year FMEA timeframe is considered to be moderate. However, this risk could be reduced to low by avoiding investigative or remedial activities above the underground workings where there is insufficient rock cover.

The Technical Memorandum prepared by Mr. Mettler is included in Appendix A of this Technical Memorandum.

5.3 EXTERNAL CAUSES

5.3.1 EARTHQUAKES

Pike Hill Mines are located in East Central Vermont and is on the currently seismically passive eastern margin of the US. The region has a complex tectonic history and there has been significant historical seismicity in the region, though there is a marked absence of mapped Quaternary seismic activity (URS, 2003). A list of historical earthquakes that were felt in Vermont is provided in Table 5-1. Note that the magnitudes were either measured (recent events) or assigned based on human perception (older events). Table 5-2 utilizes the Modified Mercalli Intensity (MMI) scale, with the intensities reported at Pike Hill Mines ranging from III (weak perceived shaking) to VI (strong perceived shaking).

Using the seismic hazard tool available on the USGS web page¹ the peak ground acceleration (PGA) for the 475, 975, and 2,475 year return period earthquakes were obtained for Pike Hill Mines, and are reported in Table 5-2. The accelerations ranging from 0.04 (4% of g) to 0.13 g (13% of g) can be associated with perceived shaking (i.e. MMI) using relationships such as those developed by Trifunac and Brady (1975) or Atkinson and Kaka (2006) for the New Madrid Area (i.e. East Coast tectonics). Table 5-3 shows the relationships between PGA and MMI used to relate the PGA calculated at the Pike Hill Mines and equivalent MMI. The expected level of shaking at the Pike Hill Mines under the 2,475 year return period is characterized as strong with potential damage as light. This level of seismicity is similar to that historically felt at the Pike Hill Mines (Table 5-1) for which no significant damage has been reported in the literature. There are also no accounts of earthquake damage occurring at the Pike Hill Mines.

Consequently, we will consider that the risk of an earthquake triggering a failure in the underground workings at Pike Hill Mines is negligible and is therefore ruled out.

5.3.2 INVESTIGATIONS

Prior to implementation of final remedies at the Pike Hill Mines, investigations and explorations will be carried out. These investigations and explorations will include intrusive work and may include, for example, drilling above and around adits to delineate the extent of the current blockages and estimate the depth of water within the underground workings. Additional work may include excavation of small volumes of waste rock, tailings, and/or soil to perform test pit explorations and other earthwork performed to construct and maintain access roads.

Based on the geologic nature of the rock as described in Appendix A and the risk of undetected voids within the rock, the risk of roof collapse during drilling that is performed in the vicinity of the underground workings may not be ruled out and is therefore considered moderate (neutral). Partial blockages may also occur when the drilling bit or cutter punches through the roof of the adit. If a collapse of the roof is detected during drilling, there should be attempts at estimating the

¹ <http://earthquake.usgs.gov/hazards/>

volume of collapsed material to assess if it could block the adit. The consequence level should then be selected based on those observations and estimations.

The risk associated with excavating some or all of the material from an adit portal to gather additional data regarding the dimensions and status of the adits should be considered moderate (neutral) to high. Any program to excavate the area near the adits will need to be preceded by activities that conclusively identify whether water is impounded and under pressure within each adit and behind the portal targeted for excavation. Because this critical information is not currently available and is not anticipated to be available prior to the RI data collection activities, excavation of the collapsed material at adit portals shall be prohibited during the initial phase of the RI field activities until and unless it can be conclusively demonstrated that the blockage does not have water accumulated behind it.

BMPs can be used to control adit and shaft releases. As part of the remedial design, a FMEA specific to the activity of adit and shaft closure should be prepared to identify appropriate BMPs and Site infrastructure necessary to contain and treat any failures modes that might be identified.

5.3.3 RAINFALL

In 2011, Hurricane Irene generated record rainfalls in Vermont. Consequently, the risk that a large rainstorm could impact Pike Hill Mines should be considered. The resulting impact from extreme rainfall would be increased infiltration into the underground workings and potential erosion of the collapsed covers over adits. Increased infiltration in the underground workings could then result in the flooding of blocked adits and/or increased discharge rates from open adits.

To assess the likelihood of such impact, the historical precipitation records for the area were reviewed. The weather data from the Corinth, VT station (ID: GHCND: 45C0043165) for the period April 2007 through April 2017 was downloaded. Daily precipitation is plotted on Figure 5-1. The station is approximately 6 miles as the crow flies from Pike Hill Mines and therefore is considered to accurately represent the weather conditions at the site.

The maximum daily total measured during that 10-year period was 5.7 inches on August 29, 2011; the day Hurricane Irene impacted Vermont.

This maximum recorded 24-hour rainfall in the vicinity of Pike Hill Mines was compared to that predicted by the Intensity Distribution Function (IDF) recommended for the State of Vermont by the Northeast Regional Climate Center for a 24-hour storm at different return periods. Figure 5-2 shows the IDF curves for return period ranging from one year to 500 years. The 5.7 inch 24-hour rainfall event corresponds to an event with a return period between 50 and 100 years. A review of a longer period of data (65 years) obtained at the Union Village Weather Station, some 18 miles away as the crow flies indicate that the areas has been subjected only 9 times in 65 years to rain event in excess of 3 inches and only twice in excess of 4 inches. The 65-year record period available at Union Village indicates that Pike Hill Mines has not been subjected to a catastrophic rain event such as a 100-year or 500-year period event. Such events could produce 6.8 inches or 8.4 inches of rain in 24 hours. Therefore, the potential impact of such large storm is considered in this FMEA as discussed in the following.

Overburden soil at the Elizabeth and Ely Mines, which are used in lieu of site specific data for the Pike Hill Mines, exhibit relatively low hydraulic conductivities. Average values reported by Nobis (Table 6-4 in Nobis 2015a) are 4.29×10^{-4} cm/s for the overburden material, 1.8×10^{-4} cm/s for the glacial till, and 3.72×10^{-4} cm/s for the bedrock. Infiltration rates of water in the soil and rocks is typically limited to a fraction of the saturated hydraulic conductivity of the material (5% to 20% typically) or on the order of 7.4×10^{-5} cm/sec for bedrock ($20\% \times 3.72 \times 10^{-4}$ m/s) which is on the order of magnitude of 2.5 inches/day. Consequently, any rainfall greater than 3 inches is not likely to result in a higher infiltration rate than a rainfall of lesser intensity. Therefore, heavy rainfall will run-off as overland flow, especially in sloping terrain.

Further, historical data and anecdotal reports suggest that mine pool levels within the Pike Hill Mines (specifically at the Eureka Mine) have remained constant over the years.

Consequently, we will consider that the risk of large rainfall events leading to an increase in seepage filling the Pike Hill underground workings is negligible and therefore ruled out.

5.3.4 SNOW COVER

Snowmelt, by contrast to rainfall, could cause an increase in recharge of the underground workings because of the slower nature of the infiltration process. Slow snow melting from the bottom will penetrate through ground cover, glacial till, and bedrock, and enter the mine workings.

Nobis recorded flows out of workings at the nearby Ely Mine once a month between July 8, 2014 and July 7, 2015. These flows are reported in Table 4-3 and on Figure 4-5 of the Ely Mine FMEA (SLR 2016a) along with the snow depth measured at the Union Village Station. The data show that the flows out of the adits tend to be highest in the spring after snowmelt. Consequently, the maximum flow rates measured at each adit in the spring will be considered as the maximum flow out of the adits.

Snow depth at the Corinth Station for the period 2007-2017 is reported on Figure 5-3. The data show that the snow depth in the winter of 2008 was on the order of 49 inches or about 1.8 times the average over the 10-year period. These 49 inches of snow translate into 4.9 inches of water. The data on Figure 5-3 also indicate that in general, it takes approximately 4-6 weeks for the snow pack to go from maximum value to zero or a melt rate of about 2×10^{-6} inch/sec. This amount is insignificant and will not affect the filling rate of the underground works rapidly enough to be a potential problem.

Looking at historical data and the current climatic trends, we will consider that the risk of large snowfall events leading to an increase in seepage filling the underground workings is negligible and therefore ruled out.

6. ANALYSIS

6.1 SMITH MINE

6.1.1 FAILURE MODES FOR SMITH MINE

For the Smith Mine, three types of major risk that could lead to uncontrolled release of MIW have been identified:

- Collapse/Blockage of an adit;
- Slope collapse or large rock falling in the mine pools leading to a surge wave; and
- Surface slope failure in overburden or glacial till blocking the adit.

Failure modes have been identified and are listed in Table 6-1. For each failure mode, it is also indicated whether the failure mode may occur naturally or may be induced by construction or investigation activities. Table 6-1 also provides an initial assessment of the data needs in order to more accurately characterize the failure mode. A total of nine failure modes were identified and labelled Failure Mode S1 through S8 with Failure Modes S1a and S1b being subsets of Failure Mode S1 to complete the full series of failure modes.

The numbering of failure modes is not describing a sequence, chronological order, or ranking of risk. Rather, the numbers were assigned based on identifying the failure modes during the FMEA process.

Consequently, in the balance of this report it may appear that numbers are out of order. To facilitate the comprehension of the numbering and order, the associated figure describing a failure mode is listed in the last column of Table 6-1. Because of their nature, figures were not developed for some of the failure modes. Such failure modes include those related to external events such as slope failure, equipment induced collapse, or removal of material in front of an adit.

For the Smith Mine, the geometry of the underground workings network is an important factor as failure modes can cascade into each other resulting in a domino effect, as described in the following for the Smith Adit:

1. Smith Adit is blocked (regardless of cause).
2. Water accumulates behind blockage, and the following can happen:
 - a. Blockage fails as soon as the Smith Adit is full, or when water within the underground workings reaches the Smith Hill Low Risk Water Level (1,657 ft AMSL). The amount of water released is at most the volume stored in the Smith Adit or approximately 36,000 gallons (Table 4-3). However, the pressure head applied to the blockage is only 8 ft (height of adit) developing a force of 16 tons (8 ft wide x 8 ft high x 8 ft of head x 62.4 pcf). Such a low pressure head is not likely to displace the amount of material needed to block the adit (which needs to be at least 8 ft wide by 8 ft tall (dimensions

of the adit) and at least 4 ft thick—assuming that the resistance to the pressure force is provided by friction between the plug and the floor and walls of the adit and the plug act as a rigid body—or a volume of 128 to 192 ft³, or approximately 16 tons of material. This is Failure Mode S1a on Table 6-1 and is depicted on Figure 6-1.

- b. Blockage fails when water has filled up the Smith Adit and Smith Shaft, or when water within the underground workings reaches the Smith Hill High Risk Water Level, which is at 1,670 ft above mean sea level (AMSL). The amount of water released is at most the volume stored in the Smith Adit, Smith Shaft, and mined area above Smith Shaft, or approximately 205,000 gallons (Table 4-3). The pressure head applied to the blockage will be on the order of 20 ft (Table 6-4). Such a pressure head will generate a force against the blockage of 40 tons (8 ft wide x 8 ft high x [20 ft of pressure head x 62 ft pcf]), or enough force to displace a full face adit plug approximately 10 ft thick or about 40 tons of material. This is Failure Mode S1b on Table 6-1 and is depicted on Figure 6-2.
- c. MIW seeps through the partially blocked Smith Adit portal. This is Failure Mode S2 on Table 6-1 and is depicted on Figure 6-3.
- d. Blockage in the Smith Adit holds and water rises to and seeps through the Smith Shaft. This is Failure Mode S3 on Table 6-1 and is depicted on Figure 6-4.
- e. Blockage in the Smith Adit holds, allowing water to rise to the high risk level (1,670 ft). Investigative drilling into the underground workings or excavations at the Smith Adit portal induces artesian discharge of MIW from the underground workings or blow-out and discharge from the portal. The amount of water released is at most the volume stored in the Smith Shaft, and mined area above Smith Shaft, or approximately 170,000 gallons (Table 4-3). The pressure head applied to the discharge will be at most on the order of 10 ft (Table 6-4). These are Failure Modes S5 and S6 on Table 6-1. S-6 is depicted on Figure 6-5.

The location of the blockage within the Smith Adit can also affect the failure type, resulting in the development of numerous failure scenarios, but assuming the blockage at the entrance of the adit is the most conservative hypothesis.

Table 6-4 reports the volume of water that can be released and the pressure head that may have built-up behind the blockage for several selected failure modes, including the worst-case failure modes. The pressure head under which the water may flow out is an indication of the damage potential of the failure mode.

6.1.2 RESULTS FOR THE SMITH MINE

6.1.2.1 Unmitigated Failure Modes

The FMEA for the unmitigated failure modes identified at Smith Mine is presented in Appendix B and summarized in the Risk Characterization Matrix on Figure 6-24.

Failure Mode S1b is identified as one of the most critical failure modes because of the volume of water released and the potential damaging nature of the release (20 ft of pressure head). The assessment of the risk associated with Failure Mode S1b is detailed in the following and is based on our knowledge of the geology, geometry of the workings, and the current conditions. The following likelihood of occurrence and consequence level are assigned:

- A low probability of occurrence (i.e. a probability of occurrence less than 10%) which corresponds to a 0.3 on the likelihood numeric scale (Table 4-1). This determination is based on the low probability of this geologic collapse and blockage occurring within the relatively short timeframe of the FMEA analysis (i.e. five years).
- The severity or consequence of this failure mode is assigned a level 3 or 300 on the consequence numeric scale (Table 4-2). The rationale for this choice is:

Based on the downgradient surface topography, blow-out of the Smith Adit would be expected to follow the topographic fall line roughly from west to east, scouring the local waste rock piles and natural site topography, endangering on-site workers or hikers.

Blow-out of MIW under Failure Mode S1b would release the water at a maximum flow rate of 1,723 cubic feet per second (ft³/sec) out of the adit portal (see Appendix B). Discharge from the adit and mobilized waste rock sediments would flow downgradient into the existing channels and ephemeral surface waters to the east and may overtop the USGS weir before entering other tributaries of the Waits Watershed, impacting the visual, chemical, and physical characteristics of the water bodies. Discharge would primarily flow through the existing channels and ephemeral surface waters at a maximum rate of 20.3 ft³/sec, with all discharged water passing the USGS weir and flowing off-site in under 5 minutes. The anticipated discharge flow paths for the failure modes associated with the Smith Adit are depicted on Figure 6-6. The discharge of MIW was modeled using Bernoulli's flow through an orifice, Manning's equation, the National Resources Conservation (NRC) Curve Number Method, and Kirpich equation and are reported in Appendix B.

Once the likelihood and severity have been established, the RPN is calculated for the failure mode:

- Failure Mode S1b RPN = Likelihood x Severity = 0.3 x 300 = 90
- Failure Mode S1b is then shown to fall in the "yellow zone" on Figure 6-24.
- Failure Modes S5, S6, and S7 are also classified in the "yellow zone" mostly because failure could be induced by activities carried out at the site and could result in injuries to workers.

Details of the calculations for each failure mode identified are shown in the tables included in Appendix B.

6.1.2.2 Mitigated Failure Modes

Mitigation measures necessary to lower the risk for each identified failure mode at Smith Mine have been considered. Because Failure Mode S1b ranks high in risk, mitigation measures that

could lower the risk are considered. The mitigation measures include site investigation and characterization activities and/or a monitoring and dewatering plan. Each mitigation measure will carry some residual risks that need to be evaluated and carry a cost that needs to be considered.

Site Investigation and Characterization: Investigation activities related to this mitigation measure would primarily focus on determining the water levels and extent of flooding within the underground workings and evaluating the ground stability in active work zones. Characterization of the underground working water levels would further aid in determining appropriate remedial actions and the relative risk levels of those actions. Water levels could be measured by lowering water level meters down open mine features like shafts, or strategically drilling boreholes into the underground workings. The adequacy of the rock cover underlying proposed investigation activities that utilize heavy equipment should also be evaluated prior to conducting any such activities. In areas where insufficient rock is possible, a surface geophysical survey could be performed to further assess the adequacy of rock cover in the vicinity of the underground workings. If the ground cover is determined to be insufficient for unrestricted weights, a heavy equipment work restriction zone should be designed and implemented based on expected ground pressures and low ground pressure equipment should be utilized for earthwork and drilling in these areas. An activity-specific FMEA should be prepared to evaluate the specific investigation/remediation activities in detail. Any conducted investigative activities should be sequenced from highest to lowest elevations with respect to adit portals to ensure worker safety in the event the underground workings are filled with water to a potential risk level.

Monitoring and Dewatering: activities related to this mitigation measure would primarily focus on containment and control of MIW. Similar to the site investigation and characterization measure, the monitoring and dewatering measure would rely heavily on the collection of water level data so appropriate and timely remedial actions are taken. To effectively manage a rise in MIW caused by a blockage of the underground workings, a dewatering system would be constructed to keep water levels of the underground workings at a safe level (<1,649 ft AMSL). Redundancy of the dewatering system extraction wells would be necessary in the event that a blockage of the underground workings occurred upgradient of a primary extraction well. In addition to a dewatering system, BMPs at the portals of mine features would be constructed to further manage any MIW not captured by the dewatering system.

By selecting either mitigation measure, the consequences of Failure Modes S1b, S5, and S7 will be reduced to a Level 2 as water levels in the underground workings would be further characterized, allowing for further appropriate remedial actions to manage any MIW to be enacted. The probability of Failure Mode S1b occurring would be further reduced by mitigation measures, however the likelihood of occurrence cannot be completely ruled out, leaving the probability at Low (Unlikely). Consequently the RPN of the mitigated Failure Mode S1b is calculated as:

- Failure Mode S1b RPN (mitigated) = Likelihood x Severity = $0.3 \times 100 = 30$

The effect of the corrective measures for Failure Mode S1b and other failure modes associated with Smith Mine are included in the FMEA Calculations in Appendix B. The risks for these failure modes were recalculated assuming mitigation measures were applied and are reported on Figure 6-25 showing that the risk ranking of a failure mode could be brought down to lower levels depending upon the mitigation measures implemented (i.e. from the “yellow zone” to the “green

zone” and even the “white zone”). The choice of a mitigation measure also has an impact on the cost of the measure as shown on the FMEA calculations where order of magnitude of cost have been included for illustration purposes only.

6.2 UNION MINE

6.2.1 FAILURE MODES FOR UNION MINE

For Union Mine three types of major risks that could lead to uncontrolled release of MIW have been identified:

- Collapse/Blockage of an adit;
- Stope collapse or large rock falling in the mine pools leading to a surge wave; and
- Surface slope failure in overburden or glacial till blocking the adit due to natural causes or during the investigations.

Failure modes for Union Mine have been identified and are listed in Table 6-2. For each failure mode, it is also indicated whether the failure mode may occur naturally or may be induced by construction or investigation activities. Table 6-2 also provides an initial assessment of the data needs in order to more accurately characterize the failure modes. A total of ten failure modes were identified and labelled Failure Mode U1 through U9 with Failure Mode U1 subdivided in Failure Modes U1a and U1b. As noted in Section 6.1.1 the numbering of failure modes is not based on any risk ranking or chronological order.

For Union Mine, the geometry of the underground workings network is an important factor as failure modes can cascade into each other in a domino effect, as described in the following for the Union Adit:

1. Union Adit is blocked (regardless of cause).
2. Water accumulates behind blockage, and the following can happen:
 - a. Blockage fails as soon as the Union Adit is full, or when water within the underground workings reaches the Union Low Risk Water Level (1,730 ft AMSL). The amount of water released is at most the volume stored in the Union Adit or approximately 310,000 gallons (Table 4-3). The pressure head applied to the blockage is on the order of 10 ft. This pressure head will generate a force of 20 tons against a full face plug in the adit (8 ft x 8 ft x 10 ft x 62.4 pcf/2000). Assuming friction resistance along floor and walls of the adit, there is enough force to displace an approximately 5 to 6 ft long blockage or about 20 to 24 tons of soil as a rigid body. This is Failure Mode U1a on Table 6-2 and is depicted on Figure 6-7.
 - b. Blockage fails when water has filled up the Union Adit, Union Shaft, and mined stope above the Union Adit, or when water within the underground workings reaches the Union High Risk Water Level (1,760 ft AMSL). The amount of water released is at most

the volume stored in the Union Adit, Union Shaft, and mined stope above the Union Adit, or approximately 365,000 gallons (Table 4-3). The pressure head applied to the blockage will be on the order of 40 ft (Table 6-4). Such a pressure head will generate a force against the blockage of 80 tons (8 ft wide x 8 ft high x [40 ft of pressure head x 62 ft pcf]), or enough force to displace a full face plug approximately 10 to 12 ft long. This is Failure Mode U1b on Table 6-2 depicted on Figure 6-8.

- c. MIW seeps through the partially blocked Union Adit portal. This is Failure Mode U2 on Table 6-2 depicted on Figure 6-9.
- d. Blockage in the Union Adit holds and water rises to and seeps through the Union Shaft. This is Failure Mode U3 on Table 6-2 depicted on Figure 6-10.
- e. Blockage in the Union Adit holds and water rises to and seeps through the Open Cut. This is Failure Mode U4 on Table 6-2 depicted on Figure 6-11.
- f. Blockage in the Union Adit holds allowing water to rise. Investigative drilling into the underground workings or excavation of the adit portal induces either artesian discharge of MIW from the underground workings or blow-out and discharge from the portal. The amount of water released is at most the volume stored in the Union Shaft, and mined stope above the Union Adit, or approximately 55,000 gallons (Table 4-3). The pressure head applied to the discharge will be at most on the order of 30 ft (Table 6-4). These are Failure Modes U6 and U7 on Table 6-2. U7 is depicted on Figure 6-12.

The location of the blockage within the Union Adit can also affect the failure type, resulting in the development of numerous failure scenarios which are not discussed herein. The blockage closest to the end of the adit being the most critical in terms of volume of water.

Table 6-4 lists for the blow-out type failure modes the amount of water that can be released and the pressure head associated with the blockage. The pressure head with which the water may flow out, and therefore velocity and energy of the flow, is an indication of the damage potential of the failure mode.

6.2.2 RESULTS FOR UNION MINE

6.2.2.1 Unmitigated Failure Modes

The FMEA for the unmitigated failure modes identified at Union Mine is presented in Appendix B and summarized in the Risk Characterization Matrix on Figure 6-26.

Failure Mode U1b is identified as the most critical failure mode because of the volume of water released and the potential catastrophic nature of the release linked to a 40-ft pressure head. The assessment of the risk associated with Failure Mode U1b is detailed in the following based on our knowledge of the geology, geometry of the workings, and the current conditions. The following likelihood of occurrence and consequence level are assigned:

- For Failure Mode U1b (and all other Union Mine failure modes that are caused by one uninduced blockage), the assigned probability of occurrence is low (i.e. a probability of occurrence less than 10%) which corresponds to a 0.3 on the likelihood numeric scale (Table 4-1). This is based on the low probability that a geologic collapse resulting in a full blockage would occur within the relatively short timeframe of the FMEA analysis (i.e. five years).
- The consequence of this failure mode is considered to be maximum impact, Level 3, corresponding to 300 on the consequence numeric scale (Table 4-2). The rationale for this choice is:

Based on the downgradient surface topography, blow-out of the Union Adit would be expected to follow the topographic fall line roughly from west to east, significantly scouring the local waste rock piles and natural site topography, endangering on-site workers or visitors.

Blow-out of MIW under Failure Mode U1b would release the water at a maximum flow of 2,436 ft³/sec out of the adit portal. Discharge from the adit and mobilized waste rock sediments would flow downgradient into the existing channels and ephemeral surface waters to the east and overtop the USGS weir before entering other tributaries of the Waits Watershed, impacting the visual, chemical, and physical characteristics of the water bodies. Discharge would primarily flow through the existing channels and ephemeral surface waters at a maximum rate of 15.3 ft³/sec, with all discharged water passing the USGS weir and flowing off-site in under 10 minutes. The anticipated discharge flow path for failure modes associated with the Union Adit are depicted on Figure 6-13. Discharge calculations associated with the Union Adit are detailed in Appendix B. Discharge of MIW was modeled using Bernoulli's flow through an orifice, Manning's equation, the NRC Curve Number Method, and the Kirpich equation.

Once the likelihood and severity have been established, the RPN can be calculated for the failure mode:

- Failure Mode U1b RPN = Likelihood x Severity = 0.3 x 300 = 90

This monitoring places failure mode U1b in the yellow zone. Failure modes U1a, U6, U7, and U8 also fell in the yellow zone because of the high impact associated with the consequence. Details of the calculations for each failure mode identified are shown in the tables included in Appendix B and the results reported on Figure 6-26.

6.2.2.2 Mitigated Failure Modes

Mitigation measures necessary to lower the risk for each identified failure mode at Union Mine have been considered. Similar to the proposed mitigation at Smith Mine, they include site investigation and characterization activities and/or a monitoring and dewatering plan. Each mitigation measure will carry some residual risks that need to be evaluated and carry a cost that needs to be considered. The two mitigation measures are described in Section 6.1.2.2.

In selecting either mitigation measure, the consequence of Failure Mode U1b would be reduced to a Level 2 as water levels in the underground workings would be further characterized, allowing

for further appropriate remedial actions to manage MIW to be enacted. The probability of Failure Mode U1b occurring would be further reduced by mitigation measures, however the probability of occurrence of the Failure Mode cannot be completely ruled out and is kept at Low (Unlikely). Consequently the RPN of the mitigated Failure Mode U1b is calculated as:

- Failure Mode U1b RPN (mitigated) = Likelihood x Severity = $0.3 \times 100 = 30$

Corrective measures were applied to Failure Mode U1b and the other failure modes associated with Union Mine and the residual risk calculated. The detailed FMEA Calculations are included in Appendix B. The recalculated risks for these failure modes assuming mitigation measures are reported on Figure 6-27 showing that the risk ranking of a failure mode could be brought down to lower levels depending upon the mitigation measures implemented (i.e. from the “orange zone” to the “green zone” and even the “white zone”). The choice of a mitigation measure also has an impact on the costs of the measure as shown on the FMEA calculations where order of magnitude of cost have been provided for illustration purposes only.

6.3 EUREKA MINE

6.3.1 FAILURE MODES FOR EUREKA MINE

For Eureka Mine the same three types of major risks identified at Smith Mine and Union Mine that could lead to uncontrolled release of MIW have been identified:

- Collapse/Blockage of an adit;
- Stope collapse or large rock falling in the mine pools leading to a surge wave; and
- Surface slope failure in overburden or glacial till blocking the adit due to natural causes or triggered by exploration.

Failure modes have been identified and are listed in Table 6-3. For each failure mode, it is also indicated whether the failure mode may occur naturally or may be induced by construction or investigation activities. Table 6-3 also provides an initial assessment of the data needs in order to more accurately characterize the failure mode. A total of thirteen failure modes were identified and labelled Failure Mode E1 through E11 with Failure Mode E1 and E2 subdivided into Failure Modes E1a, E1b, E2a, and E2b.

As mentioned in Section 6.1.1, the numbering of failure modes is not related to an initial risk assessment or a chronological order. Rather, the numbers were assigned based on the order the failure modes were identified during the FMEA process. Consequently, in the balance of this report it may appear that numbers are out of order. To facilitate the comprehension of the numbering and order, the figure number describing a failure mode is listed in the last column of Table 6-3.

Similarly to the other mines, the geometry of the underground workings network at Eureka Mine is an important factor as failure modes can cascade into each other in a domino effect, as described in the following for the Eureka Lower and Upper Adits:

1. Eureka Lower Adit is blocked (regardless of cause).

2. Water accumulates behind a full blockage in the Eureka Lower Adit (Figure 6-14), and the following can happen:
 - a. Blockage fails as soon as the Eureka Lower Adit is full, or when water within the underground workings reaches the Eureka Lower Adit Low Risk Water Level (1,830 ft AMSL). The amount of water released is at most the volume stored in the Eureka Lower Adit and Open Area below Bedrock Area 2, or approximately 480,000 gallons (Table 4-3). The pressure head applied to the blockage will be on the order of 30 ft (Table 6-4). Such a pressure head will generate a force against the blockage of 60 tons (8 ft wide x 8 ft high x [30 ft of pressure head x 62 ft pcf]), or enough force to displace a full face plug approximately 17 ft long. This is Failure Mode E1a on Table 6-3 and is depicted on Figure 6-14.
 - b. Eureka Lower Adit blockage holds and water levels rise above Eureka Lower Adit Low Risk Water Level (1,830 ft AMSL). At the same time, the Eureka Lower Shaft becomes blocked (regardless of cause) and the Eureka Upper Adit is fully blocked (regardless of cause), resulting in a simultaneous, uninduced blockage of both the Eureka Lower Adit, Eureka Lower Shaft, and Eureka Upper Adit. Water accumulates behind blockage in the Eureka Upper Adit (Figure 6-16), and the following can happen:
 - › Eureka Lower Adit Blockage fails when water has filled up the Eureka Lower Adit, Eureka Lower Shaft, Eureka Upper Adit, Cuprum Shaft, and all Open Areas, or when water within the underground workings reaches the Eureka Upper/Lower Adit High Risk Water Level (1,955 ft AMSL). The amount of water released is at most the volume stored in the Eureka Lower Adit, Eureka Lower Shaft, Eureka Upper Adit, Cuprum Shaft, and all Open Areas, or approximately 5,000,000 gallons (Table 4-3). The pressure head applied to the blockage will be on the order of 155 ft (Table 6-4). Such a pressure head will generate a force against the blockage of 310 tons (8 ft wide x 8 ft high x [155 ft of pressure head x 62 ft pcf]), or enough force to displace a full face plug approximately 90 ft long or 360 tons of material approximately 20 ft long. This is Failure Mode E1b on Table 6-3 and is depicted on Figure 6-15.
 - › Eureka Upper Adit blockage fails as soon as the Eureka Upper Adit is full, or when water within the underground workings reaches the Eureka Upper Adit Low Risk Water Level (1,900 ft AMSL). The amount of water released is at most the volume stored in the Eureka Lower Adit and Open Area 2, or approximately 475,000 gallons (Table 4-3). The pressure head applied to the blockage will be on the order of 8 ft (Table 6-4). Such a pressure head will generate a force against the blockage of 16 tons (8 ft wide x 8 ft high x [8 ft of pressure head x 62 ft pcf]). This is Failure Mode E2a on Table 6-3 and is depicted on Figure 6-16.
 - › Eureka Upper Adit blockage fails when water has filled up the Eureka Lower Adit, Eureka Lower Shaft, Eureka Upper Adit, Cuprum Shaft, and all Open Areas, or when water within the underground workings reaches the Eureka Upper/Lower Adit High Risk Water Level (1,955 ft AMSL). The amount of water released is at most the volume stored in the Eureka Upper Adit, Open Area 1 and 2, and Cuprum

Shaft, or approximately 1,875,000 gallons (Table 4-3). The pressure head applied to the blockage will be on the order of 63 ft (Table 6-4). Such a pressure head will generate a force against the blockage of 125 tons (8 ft wide x 8 ft high x [63 ft of pressure head x 62 ft pcf]). This is Failure Mode E2b on Table 6-3 and is depicted on Figure 6-17.

3. Various mine features are blocked (regardless of cause):
 - a. MIW seeps through the partially blocked Eureka Lower Adit portal. This is Failure Mode E3 on Table 6-3 and is depicted on Figure 6-18. It is noted that E3 depicts a condition that is analogous to current conditions.
 - b. MIW seeps through the partially blocked Eureka Upper Adit portal. This is Failure Mode E4 on Table 6-3 and is depicted on Figure 6-19. Failure Mode E4 would require the simultaneous, uninduced blockage of both the Eureka Lower Adit and Eureka Lower Shaft.
 - c. Blockage in the Eureka Lower Adit holds and water rises to and seeps through the Eureka Lower Shaft. This is Failure Mode E5 on Table 6-3 and is depicted on Figure 6-20.
 - d. Blockage in the Eureka Upper Adit holds and water rises to and seeps through the Cuprum Shaft. This is Failure Mode E6 on Table 6-3 and is depicted on Figure 6-21. Failure Mode E6 would require the simultaneous, uninduced blockage of both the Eureka Lower Adit, the Eureka Lower Shaft, and the Eureka Upper Adit.
 - e. Blockage in either adits allowing water to rise. Investigative drilling into the underground workings induces artesian discharge of MIW from the underground workings. The amount of MIW released is at most the volume stored in the Eureka Upper Adit, Cuprum Shaft, and all Open Areas or approximately 4,525,000 gallons (Table 4-3). The pressure head applied to the discharge could be up to 140 ft (Table 6-4). This is Failure Mode E9 on Table 6-3 and is depicted on Figure 6-22. Failure Mode E9 would require the simultaneous, uninduced blockage of both the Eureka Lower Adit, the Eureka Lower Shaft, and the Eureka Upper Adit.

The location of the blockage within the Eureka Mine underground workings can also affect the failure type, resulting in the development of numerous failure scenarios. These scenarios are not discussed herein. The assumption is that the blockage is at the end of the adit which is the most conservative assumption (largest amount of water stored).

Table 6-4 lists for the blow-out type failure modes the amount of MIW that could be released and the pressure head associated with the blockage. The pressure head under which the MIW flows out is an indication of the damage potential of the failure mode.

6.3.2 RESULTS FOR EUREKA MINE

6.3.2.1 Unmitigated Failure Modes

The FMEA for the unmitigated failure modes identified at Eureka Mine are presented in Appendix B and summarized in the Risk Characterization Matrix on Figure 6-28.

The assigned probability for all Eureka Failure modes caused by one uninduced geologic collapse resulting in full blockage is low. This determination is based on the low probability of this type of failure occurring within the relatively short timeframe of the FMEA analysis (i.e. five years).

The assigned probability for all Eureka Failure modes caused by a combination of two or more uninduced geologic collapses resulting in full blockage is ruled out. This determination is based on the highly unlikely probability that this type of multiple-failure would occur within the relatively short timeframe of the FMEA analysis (i.e. five years).

Failure Mode E1a is identified as the most critical failure mode because of the volume of MIW that could be released and the catastrophic nature of the release due to the 30 ft of pressure head. Based on our knowledge of the geology, geometry of the workings, and the current conditions, the following likelihood of occurrence and consequence levels are assigned:

- A low probability of occurrence (i.e. a probability of occurrence less than 1%) which corresponds to 0 on the likelihood numeric scale (Table 4-1);
- The severity or consequence of this failure mode is maximum impact Level 3, a value of 300 on the consequence numeric scale (Table 4-2). The rationale for this choice is described in the following:

Based on the downgradient surface topography, blow-out of the Eureka Lower Adit would be expected to follow the topographic fall line roughly from west to east, significantly scouring the local waste rock piles and natural site topography, endangering on-site workers or downstream populations.

Blow-out of MIW under Failure Mode E1b would release the MIW at a maximum flow of 2,110 ft³/sec out of the adit portal. Discharge from the adit and mobilized waste rock sediments would flow downgradient into the existing channels and ephemeral surface waters to the east and overtop the USGS weir before entering other tributaries of the Waits Watershed, impacting the visual, chemical, and physical characteristics of the water bodies. Discharge would primarily flow through the existing channels and ephemeral surface waters at a maximum rate of 16.2 ft³/sec, with all discharged water passing the USGS weir and flowing off-site in under 10 minutes. The anticipated discharge flow path for failure modes associated with the Eureka Lower Adit are depicted on Figure 6-23. Discharge calculations associated with the Eureka Lower Adit are detailed in Appendix B. Discharge of MIW was modeled using Bernoulli's flow through an orifice, Manning's equation, the NRC Curve Number Method, and the Kirpich equation.

Once the likelihood and severity have been established, the RPN can be calculated for the failure mode:

- Failure Mode E1a RPN = Likelihood x Severity = $0.3 \times 300 = 90$
- Failure Mode E1a is then shown to fall in the “yellow zone” on Figure 6-28.
- Failure Modes E10 and E11 are also classified in the “yellow zone” mostly because these failures could be induced by activities carried out at the site and could result in injuries to workers.

Details of the calculations for each failure mode identified are shown in the tables included in Appendix B.

6.3.2.2 Mitigated Failure Modes

Mitigation measures necessary to lower the risk for each identified failure mode at Eureka Mine have been considered and summarized in Appendix B.

These mitigation measures include site investigation and characterization activities and/or a monitoring and dewatering plan. Each mitigation measure will carry some residual risks that need to be evaluated and carry a cost that needs to be considered. These two mitigation measures were described in Section 6.1.2.2.

In selecting either mitigation measure, the consequence of Failure Mode E1a will be reduced to at least Level 2 as water levels of the underground workings would be further characterized, allowing for further appropriate remedial actions to manage any released MIW. The probability of Failure Mode E1a occurring may be further reduced by mitigation measures, however the probability cannot be completely ruled out, therefore implementing of one of the mitigation measures keeps the probability low. Consequently the RPN of the mitigated Failure Mode E1a is calculated as:

- Failure Mode E1a RPN (mitigated) = Likelihood x Severity = $0.3 \times 100 = 30$

The effect of the mitigation measures on Failure Mode E1a and other failure modes associated with Eureka Mine are recalculated in the FMEA Calculations included in Appendix B. The risks for these failure modes were recalculated assuming mitigation measures and are shown on Figure 6-29 showing that the risk ranking of a failure mode could be brought down to lower levels depending upon the mitigation measures implemented (i.e. down from the “orange zone” to the “green zone” and even the “white zone”). The choice of a mitigation measure also has an impact on the costs of the measure as shown on the FMEA calculations where order of magnitude of cost have been provided for illustration purposes only.

7. SUMMARY AND CONCLUSIONS

7.1 SUMMARY

A FMEA was performed for the underground workings of the Pike Hill Mines which includes the Smith Mine, the Union Mine, and the Eureka Mine located in Corinth, Vermont. The focus of the FMEA was to identify the failure modes that could contribute to a sudden, uncontrolled release of MIW from the mine underground workings in excess of the ability of the infrastructure available at the site to contain and treat the discharge.

The FMEA considered only one phase in the time dependent process of investigation and remediation of the Pike Hill Mines Complex:

Current Conditions and Investigation: which covers the period until investigation is completed and is assumed to up to 5 years in duration. Such investigation activities may include: minor earthwork for access road construction/maintenance; overburden and bedrock drilling, including bedrock drilling into the adits from the ground surface; geophysical exploration; and minor excavations (e.g. test pits) for the purposes of sample collection.

A likelihood scale and a consequence scale were established based on the probability of occurrence of the failure modes identified and their associated consequences.

For each failure mode, a corrective action, remediation, or mitigation measures have been suggested and the risk re-evaluated for each failure mode assuming implementation of those measures.

The FMEA identified one critical failure mode at each mine based on its probability of occurrence and consequence:

- **Smith Mine Failure Mode S1b:** This failure mode is associated with the formation of a blockage in the Smith Adit, regardless of its origin, and its subsequent catastrophic failure. Failure Mode S1b would result in the sudden and uncontrolled release of up to 205,000 gallons of MIW under approximately 60 ft of pressure head, potentially causing erosion, scouring, and damage to site features such as the waste rock piles, roads, and surface water of the Waits Watershed. Visual, chemical, and physical impacts to water quality of the Waits Watershed water bodies would be observed. Mitigation measures to reduce the risks associated with Failure Mode S1b are suggested in the FMEA calculations included in Appendix B and the resulting risk for Failure Mode S1b was recalculated assuming mitigation measures were applied). The results demonstrate that mitigation measures could reduce the RPN for Failure Mode S1b from 90 (“Orange Zone”) to 30 (“Green Zone”).
- **Union Mine Failure Mode U1b:** This failure mode is associated with the formation of a blockage in the Union Adit, regardless of its origin, and its subsequent catastrophic failure. Failure Mode U1b would result in the sudden and uncontrolled release of up to 365,000 gallons of MIW under approximately 40 ft of pressure head, potentially causing erosion, scouring, and damage to site features such as the waste rock piles, roads, and surface

water of the Waits Watershed. Visual, chemical, and physical impacts to water quality of the Waits Watershed water bodies would be observed. Mitigation measures to reduce the risks associated with Failure Mode U1b are suggested in the FMEA calculations included in Appendix B. The resulting risk for Failure Mode U1b was recalculated assuming that one of the mitigation measures was applied. The results show the RPN for Failure Mode U1b drops from 90 to 30.

- Eureka Mine Failure Mode E1a: This failure mode is associated with the formation of a blockage in the Eureka Lower Adit, regardless of its origin, and its subsequent catastrophic failure. Failure Mode E1a would result in the sudden and uncontrolled release of up to 480,000 gallons of adit discharge water under approximately 30 ft of pressure head, potentially causing significant erosion, scouring, and damage to site features such as the waste rock piles, roads, and surface water of Pike Hill Brook. Visual, chemical, and physical impacts to water quality of Pike Hill Brook would be observed. Mitigation measures to reduce the risks associated with Failure Mode E1a are suggested in the FMEA calculations included in Appendix B. The resulting risk for Failure Mode E1a was recalculated assuming that mitigation measures were applied. The results show that some mitigation or corrective measure could reduce the RPN for Failure Mode E1a from 90 to 30.

7.2 CONCLUSIONS

The following conclusions are drawn from FMEA conducted for the underground workings of the Pike Hill Mines:

- Under current conditions, both the risk of catastrophic failure and associated MIW release from identified adits at all three mines are low.
- Prior to construction and investigation, it is recommended to investigate further the conditions near the portals of the Smith, Union, and Eureka Upper Adits.
- During construction, it is recommended to anticipate and develop contingency plans and possibly add site infrastructure to manage and treat a possible release of larger volumes of MIW than currently measured should a portal blockage be present in one of the adits.
- During construction, low ground pressure equipment should be considered when near the portal or roof of an adit to minimize loading the roof and walls.

8. REFERENCES

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TABLES

Table 3-1: Pike Hill FMEA Underground Workings Naming Convention and Statuses

MINE WORKINGS TYPE	CURRENT NAME USED IN FMEA	ALTERNATE/PREVIOUS ALIAS (PAL 2011)	ALTERNATE/PREVIOUS ALIAS (NOBIS CSM 2008)	CURRENT STATUS AND INFORMATION
SMITH MINE				
Shaft	Smith Shaft	Smith Shaft	Shaft	- Shaft open
Adit	Smith Adit	Smith Adit	- Main Adit - Smith Collapsed Adit	- Portal partly collapsed to unknown extent - Air flow through adit
UNION MINE				
Shaft	Union Shaft	Union Shaft	Shaft	- Shaft open
Adit	Union Adit	Union Adit	Main Adit	- Portal collapsed to unknown extent - Seepage through portal - Unknown water level within adit
EUREKA MINE				
Shaft	Cuprum Shaft	Cuprum Shaft	Cuprum Shaft	- Shaft open (located within open cut)
Adit	Eureka Upper Adit	Eureka Upper Adit	Upper Adit	- Portal collapsed to unknown extent
Shaft	Eureka Lower Shaft	Eureka Shaft	Eureka Shaft	- Shaft open (located within open cut)
Adit	Eureka Lower Adit	Eureka Lower Adit	Main Adit Eureka Adit	- Portal open with no visible collapses - Water pooling at portal

Table 4-1: Likelihood Definitions and Scale

LIKELIHOOD	DESCRIPTIONS	PROBABILITY OF OCCURRENCE FOR PERIOD UNDER CONSIDERATION	LIKELIHOOD NUMERIC SCALE
Ruled Out (Negligible)	The physical conditions do not exist for its development or the likelihood is so remote as to be non-credible.	<0.1%	0
Low (Unlikely)	The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred in the past or that a condition or flaw exists that could lead to its development in the future.	>0.1% and < 10%	0.3
Moderate (Neutral)	The fundamental condition or defect is known to exist or indirect evidence suggests it is plausible, but evidence is not weighted toward likely or unlikely.	>10% and <50%	1
High (Likely)	There is direct evidence or substantial indirect evidence to suggest it has occurred and/or is likely to occur.	>50%	3

Table 4-2: Consequence Definitions and Scale

CONSEQUENCE LEVEL	DESCRIPTION	CONSEQUENCE NUMERIC SCALE
Level 0 - No Significant Consequences	No significant economic consequences or impacts to the downstream population. Any release will be of a volume and chemistry within the range of what is currently taking place under current site conditions.	0
Level 1	No significant economic impacts to the downstream population (loss of road use or damage to property); water quality within site (ephemeral streams) may experience degraded water quality for a limited period of time but no significant impacts to major surface waters of the Waits Watershed. Minor erosion of waste rock piles and access roads may occur and minor repairs may be necessary.	30
Level 2	No significant economic impacts to the downstream population (loss of road use or damage to property); water quality with site and downstream in ephemeral streams and other surface waters of the Waits Watershed are adversely impacted to an extent greater than current impacts for a short period of time. Extensive visual/aesthetic impacts for a short period of time. Moderate erosion on-site (waste rock piles) requiring repair, possible short-term loss of use of site access roads.	100
Level 3 – Maximum Impact	Economic impacts to the downstream population (loss of road use and property damage); water quality within site and downstream in ephemeral streams and other surface waters of the Waits Watershed are adversely impacted to an extent greater than current impacts for an extended period of time. Extensive visual/aesthetic impacts. Major erosion on-site (waste rock piles) requiring substantial repair, possible extended loss of use of site access roads.	300

Table 4-3: Estimated Volumes of Pike Hill Mines Underground Workings

Location	Feature Type	Feature Name	Dimensions (ft) ¹				Total Volume (gal)	Average Seepage Rate ² (gpm)	Max Seepage Rate ³ (gpm)	Min Time to Fill ³ (days)	Max Time to Fill ³ (days)
			Length	Width	Height	Comments / References					
Smith Hill Mine	Shaft	Smith Shaft	8	15	15	- Height calculated from intersection with known adjoining mine features - Length and Width from PAL, 2011 page 188	13,464	50	200	0.0	0.2
	Adit	Smith Adit	75	8	8	- Length from PAL, 2011 page 188 - Width and Height approximated from site photos and similar historic features	35,904	50	200	0.1	0.5
	Stope	Unnamed Stope	65	10	10	- Length calculated from intersection with Smith Adit to static water level (1,610 AMSL) - Width and Height approximated from similar historic features	48,620	50	200	0.2	0.7
	Cavern	Unnamed Mined Area Above Smith Shaft	-	-	8	- Area calculated from extent of underground workings shown on 2017 Nobis X-Section and Plan View of Underground Workings Extent, represents the maximum potential cavern volume above the Smith Adit - Height approximated from similar historic features	155,584	50	200	0.5	2.2
Union Mine	Shaft	Union Shaft	15	6	30	- Dimensions from PAL 2011 page 103 - Height calculated from intersection with known adjoining mine features	20,196	50	200	0.1	0.3
	Adit	Union Adit	300	8	8	- Length from PAL 2011 page 110 - Width and Height approximated from site photos and similar historic features - Adit volume based on 2017 Nobis X-Section Plan view	309,672	50	200	1.1	4.3
	Stope	Unnamed Stope	70	8	8	- Width and Height from PAL 2011 page 103 - Length calculated from 2017 Nobis X-Section and Plan View of Underground Workings Extent (length of stope above Union Adit)	33,510	50	200	0.1	0.5
Eureka Mine	Shaft	Cuprum Shaft	135	8	8	- Length calculated from 2017 Nobis X-Section and Plan View of Underground Workings Extent (length of shaft to intersection with Open Area 2) - Length and Width approximated from site photos and similar historic features	64,627	50	200	0.2	0.9
		Eureka Lower Shaft	8	15	40	- Height calculated from intersection with known adjoining mine features - Length and Width approximated from site photos and similar historic features	35,904	50	200	0.1	0.5
	Adit	Eureka Upper Adit	112	8	8	- Length 112 ft from PAL, 2011 page 141 - Width and Height approximated from site photos and similar historic features	53,617	50	200	0.2	0.7
		Eureka Lower Adit	1000	8	8	- Length 500-1000 ft from PAL, 2011 page 141 (used conservative estimate of 1,000 ft to account for unknown extent and dimensions of caverns/openings at Eureka Lower Adit elevation) - Width and Height approximated from site photos and similar historic features	478,720	50	200	1.7	6.6
	Cavern	Open Area 1	-	-	8	- Area calculated from extent of underground workings shown on 2017 Nobis X-Section and Plan View of Underground Workings Extent, represents the maximum potential cavern volume of Open Area 1 - Height approximated from similar historic features	1,334,432	50	200	4.6	18.5
		Open Area 2	-	-	8	- Area calculated from extent of underground workings shown on 2017 Nobis X-Section and Plan View of Underground Workings Extent, represents the maximum potential cavern volume of Open Area 2 - Height approximated from similar historic features	418,282	50	200	1.5	5.8
		Open Area Below Bedrock Area 2	-	-	25	- Dimensions calculated from 2017 Nobis X-Section and Plan View of Underground Workings Extent	2,618,000	50	200	9.1	36.4
		Opening to Lower Workings	8	25	30	- Width and Height calculated from 2017 Nobis X-Section and Plan View of Underground Workings Extent (height of cavern to intersection with static water level at 1,800 ft AMSL) - Length approximated from similar historic features	44,880	50	200	0.2	0.6

Notes:

- = dimensions approximated from site photos and/or similar historic mine features
- = dimensions calculated utilizing other known dimensions, locations, strikes

¹ Dimensions from PAL, 2011 and approximated from mine drawings when not given.

² Minimum and maximum equilibrium recharge rates are the composite averages of the min/max values from neighboring Ely/Elizabeth Mines.

³ Time to fill = Total Volume / Discharge rate, assuming approximate mine pool elevations of 1610, 1720, 1800 for Smith, Union and Eureka Mines, respectively (PAL, 2011).

Table 5-1: Large Earthquakes Felt in Vermont

YEAR	LOCATION	MAGNITUDE	MMI RANGE IN VERMONT
1732	Montreal, Quebec	5.8	VI-IV
1925	La Malbaie, Quebec	6.5	IV-III
1935	Timiskaming, Quebec	6.1	IV-III
1940	Ossipee, N.H.	5.5	VI-IV
1944	Massena, N.Y.	5.2	V-IV
1973	Maine-N.H.-Quebec border	4.8	V-III
1982	Gaza, N.H.	4.7	IV-III
1983	Goodnow, N.Y.	5.1	IV-III
1988	Saqueney, Quebec	6.2	V-IV

Table 5-2: Peak Ground Acceleration, Return Period at Pike Hill Mine, and Mercalli Intensity

Probability of Occurrence	Return Period (Years)	PGA (% of g)	MMI	Perceived Shaking	Potential Damage
10% in 50 years	475	4	V	Moderate	Very light
2% in 50 years	2,475	13	VI	Strong	Light
1% in 50 years	4,975	20	VII	Very Strong	Moderate

Table 5-3: Relationships between Acceleration and Mercalli Intensity

Perceived Shaking	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	None	None	None	Very light	Light	Moderate	Moderate-Heavy	Heavy	Very heavy
Peak Ground Acceleration (% g)	<0.17	0.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
Peak Velocity (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
MMI (Trifunac and Brady, 1975)	I	II-III	IV	V	VI	VII	VIII	IX	X+
MMI (Atkinson and Kaka, 2006)	I-II	III	IV	V	VI	VII	VIII	IX	X

Table 6-1: Identified Failure Modes – Smith Hill

MINE	N°	FAILURE MODE	INDUCED	DATA NEED	Figure
Smith Hill	S1a	Blow-out with violent discharge of the Smith Adit due to rising pressure/water levels behind blockage in the Smith Adit and water levels at the Low Risk Level (1,655 ft AMSL)	NO	Water Levels	6-1
	S1b	Blow-out with violent discharge of the Smith Adit due to rising pressure/water levels behind blockage in the Smith Adit and water levels at the High Risk Level (1,670 ft AMSL)	NO	Water Levels	6-2
	S2	Slow discharge from the Smith Adit due to rising water levels behind partial blockage in the Smith Adit	NO	Water Levels	6-3
	S3	Slow discharge from the Smith Shaft due to rising water levels behind full blockage in the Smith Adit	NO	Water Levels	6-4
	S4	Any noninduced surface slope failure resulting in blockage of adit	NO	None	-
	S5	Discharge or blow-out of the Smith Adit due to excavation of debris/waste in front of adit portal and water levels above the Safe Level (1,647 ft AMSL)	YES	Water Levels	-
	S6	Artesian discharge from underground workings due to investigative drilling into the underground workings and water levels above drilling elevation	YES	Water Levels	6-5
	S7	Equipment induced collapse of adit hanging wall	YES	Geology, Depth of Adit Hanging Wall	-
	S8	Any investigation induced surface slope failure resulting in blockage of adit or shaft	YES	Equipment Type	-

Notes:

- Assumed static water level of 1,610 ft AMSL from description of mine flooding in PAL, 2011 page 188

Table 6-2: Identified Failure Modes – Union Mine

MINE	N°	FAILURE MODE	INDUCED	DATA NEED	Figure°
Union Mine	U1a	Blow-out with violent discharge of the Union Adit due to rising pressure/water levels behind blockage in the Union Adit and water levels at the Low Risk Level (1,730 ft AMSL)	NO	Water Levels	6-7
	U1b	Blow-out with violent discharge of the Union Adit due to rising pressure/water levels behind blockage in the Union Adit and water levels at the High Risk Level (1,760 ft AMSL)	NO	Water Levels	6-8
	U2	Slow discharge from the Union Adit due to rising water levels behind partial blockage in the Union Adit	NO	Water Levels	6-9
	U3	Slow discharge from the Union Shaft due to rising water levels behind full blockage in the Union Adit	NO	Water Levels	6-10
	U4	Slow discharge from Open Cut due to rising water levels behind full blockage in the Union Adit	NO	Water Levels	6-11
	U5	Any noninduced surface slope failure resulting in blockage of adit	NO	None	-
	U6	Discharge or blow-out of the Union Adit due to excavation of debris/waste in front of adit portal and water levels above the Safe Level (1,720 ft AMSL)	YES	Water Levels	-
	U7	Artesian discharge from underground workings due to investigative drilling into the underground workings and water levels above drilling elevation	YES	Water Levels	6-12
	U8	Equipment induced collapse of adit hanging wall	YES	Geology, Depth of Adit Hanging Wall	-
	U9	Any investigation induced surface slope failure resulting in blockage of adit or shaft	YES	Equipment Type	-

Notes:

- Assumed static water level of 1,723 ft AMSL from seepage/water pooling at Union Adit portal

Table 6-3: Identified Failure Modes – Eureka Mine

MINE	N°	FAILURE MODE	INDUCED	DATA NEED	Figure°
Eureka Mine	E1a	Blow-out with violent discharge of the Eureka Lower Adit due to rising pressure/water levels behind blockage in the Eureka Lower Adit and water levels at the Eureka Lower Adit Low Risk Level (1,830 ft AMSL)	NO	Water Levels	6-14
	E1b	Blow-out with violent discharge of the Eureka Lower Adit due to rising pressure/water levels behind blockage in the Eureka Lower Adit, Eureka Lower Shaft, and Eureka Upper Adit and water levels at the Eureka Lower Adit High Risk Level (1,955 ft AMSL)	NO	Water Levels	6-15
	E2a	Blow-out with violent discharge of the Eureka Upper Adit due to rising pressure/water levels behind blockage in the Eureka Upper Adit and water levels at the Eureka Upper Adit Low Risk Level (1,900 ft AMSL)	NO	Water Levels	6-16
	E2b	Blow-out with violent discharge of the Eureka Upper Adit due to rising pressure/water levels behind blockage in the Eureka Lower Adit, Eureka Upper Adit, Eureka Lower Shaft, and Eureka Upper Adit and water levels at the Eureka Upper Adit High Risk Level (1,955 ft AMSL)	NO	Water Levels	6-17
	E3	Slow discharge from the Eureka Lower Adit due to rising water levels behind partial blockage in the Eureka Lower Adit	NO	Water Levels	6-18
	E4	Slow discharge from the Eureka Upper Adit due to rising water levels behind partial blockage in the Eureka Upper Adit	NO	Water Levels	6-19
	E5	Slow discharge from the Eureka Lower Shaft due to rising water levels behind full blockage in the Eureka Lower Adit	NO	Water Levels	6-20
	E6	Slow discharge from the Cuprum Shaft due to rising water levels behind full blockages in lower underground workings	NO	Water Levels	6-21
	E7	Any non-induced surface slope failure resulting in blockage of adit	NO	None	-
	E8	Discharge or blow-out of the Eureka Upper Adit due to excavation of debris/waste in front of adit portal and water levels above the Eureka Upper Adit Safe Level (1,890 ft AMSL)	YES	Water Levels	-
	E9	Artesian discharge from underground workings due to investigative drilling into the underground workings and water levels above drilling elevation	YES	Water Levels	6-22
Eureka Mine	E10	Equipment induced collapse of adit hanging wall	YES	Equipment Type	-
	E11	Any investigation induced surface slope failure resulting in blockage of adit or shaft	YES	Equipment Type	-

Notes:

- Assumed static water level of 1,800 ft AMSL from seepage/water pooling at Eureka Lower Adit portal
- Assumed connectivity between Eureka Upper and Eureka Lower Adit between Bedrock Area 2 based on description in PAL, 2011 page 141

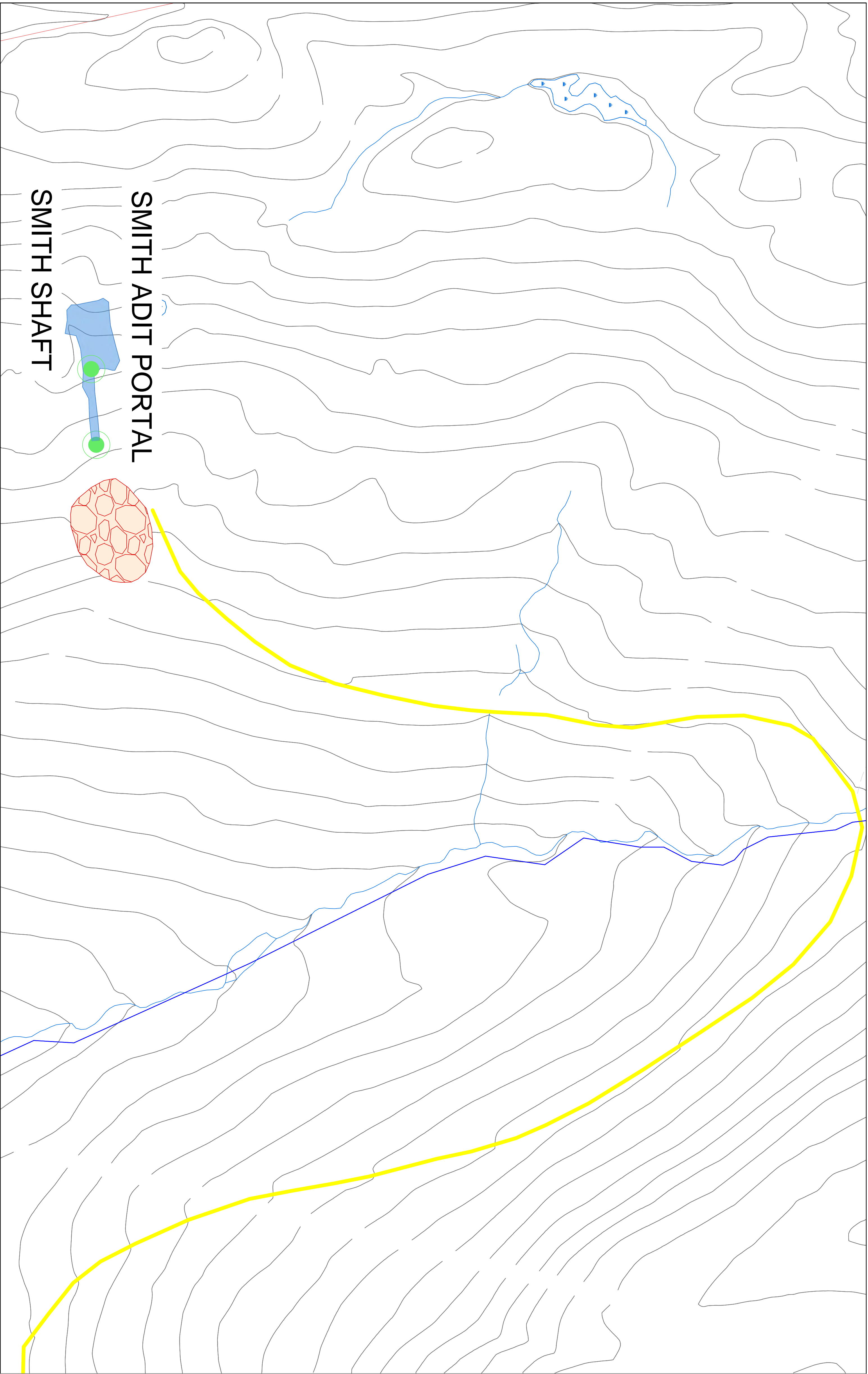
Table 6-4: Selected Failure Modes: Discharge Volumes, Heads, and Fill Times

Blow-out Failure Mode Characterization						
Mine	Failure Mode Number	Volume of Water Blown-out (gal)	Head (ft)	Pressure (tons)	Minimum Time to Fill ¹ (days)	Maximum Time to Fill ¹ (days)
Smith Hill	S1a	36,000	8	16	0.3	1.2
	S1b	205,000	20	40	0.9	3.5
Union Mine	U1a	310,000	10	20	1.1	4.3
	U1b	365,000	40	80	1.3	5.0
Eureka Mine	E1a	480,000	30	60	1.8	7.3
	E1b	5,000,000	155	310	17.5	70.1
	E2a	475,000	8	16	12.7	50.7
	E2b	1,875,000	63	125	17.5	70.1









Notes:

¹. Time to fill = Total Volume / Discharge rate, assuming approximate mine pool elevations of 1610, 1720, 1800 for Smith, Union and Eureka Mines, respectively (PAL, 2011).

FIGURES



LEGEND:

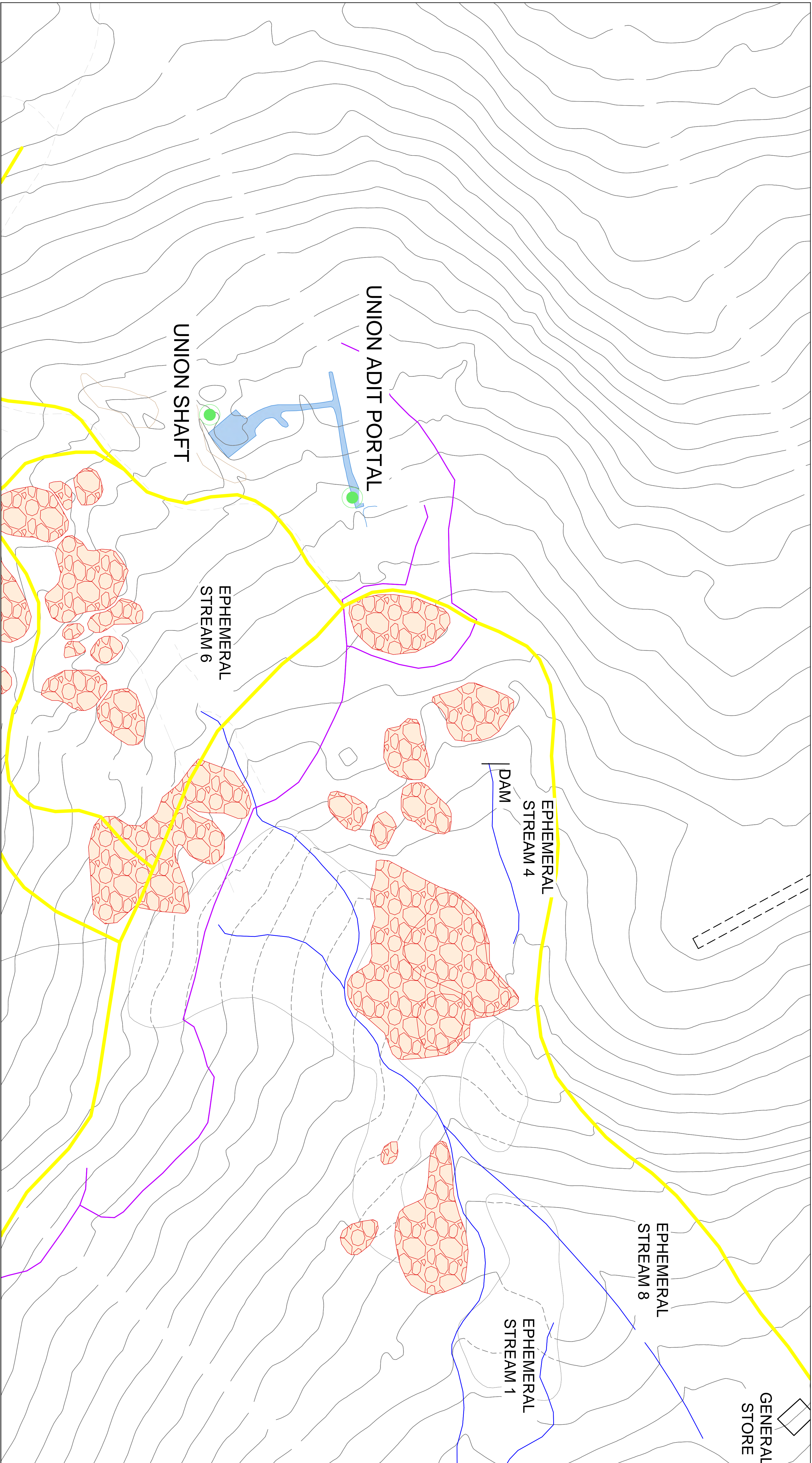
-  = WASTE ROCK PILE
-  = UNDERGROUND WORKINGS POTENTIALLY AVAILABLE FOR DISCHARGE
-  = ROAD
-  = OPENING TO UNDERGROUND WORKINGS
-  = EPHEMERAL CREEK / SURFACE WATER
-  = EXISTING CHANNEL
-  = EXISTING STRUCTURE
-  = OPEN CUT

REPORT

PIKE HILL FMEA

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- LEGEND:**

 - = WASTE ROCK PILE
 - = ROAD
 - = FAILURE MODE RELEASE POINT
 - = FAILURE MODE DISCHARGE PATH
 - = EPEMERAL CREEK/ SURFACE WATER
 - = EXISTING CHANNEL
 - = EXISTING STRUCTURE
- FAILURE MODE CHARACTERISTICS:**

FAILURE MODE U1A:

 - DISCHARGE VOLUME = 310,000 GALLONS
 - HEAD = 10 FT

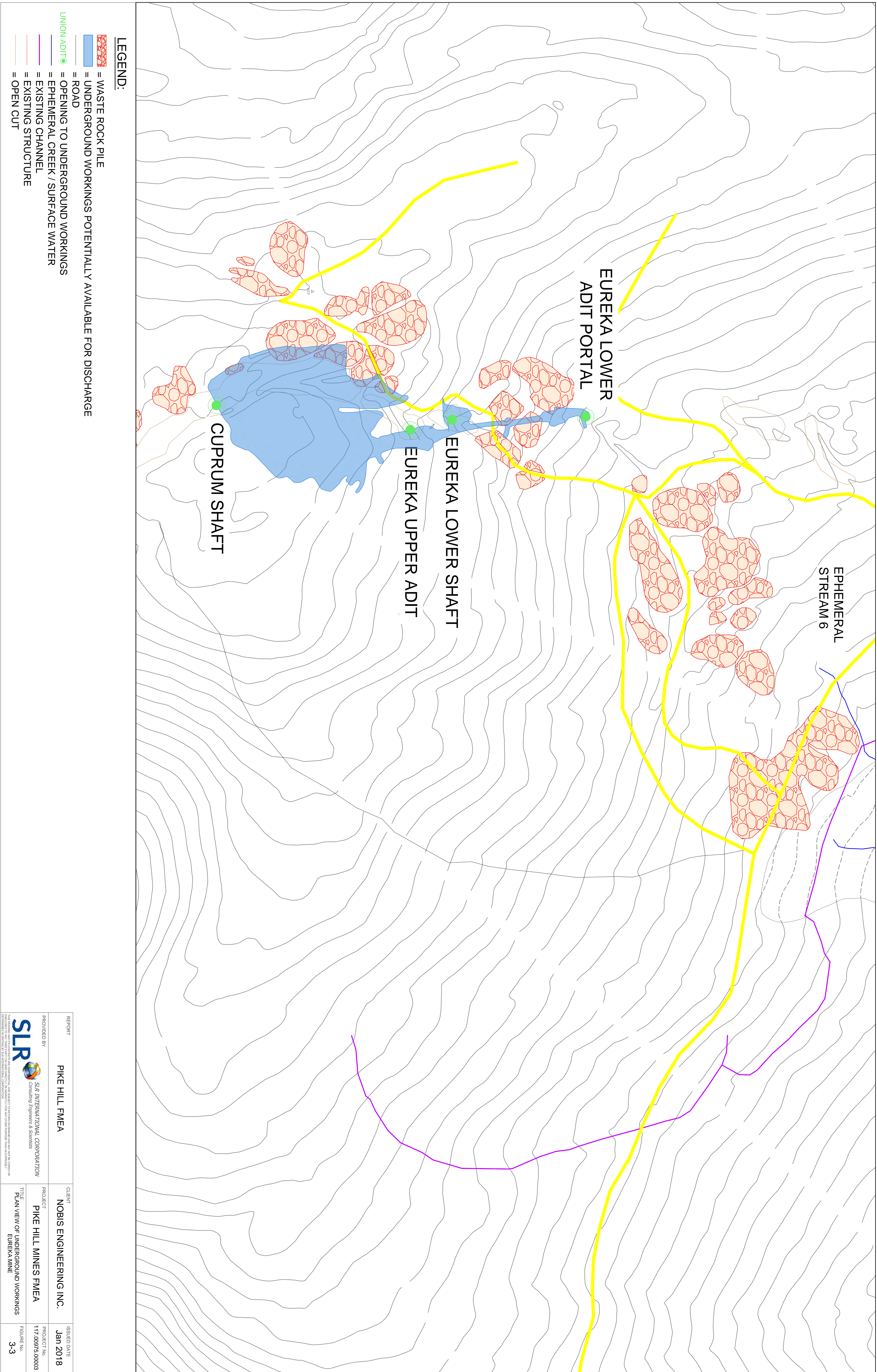
FAILURE MODE U1B:

 - DISCHARGE VOLUME = 365,000 GALLONS
 - HEAD = 40 FT

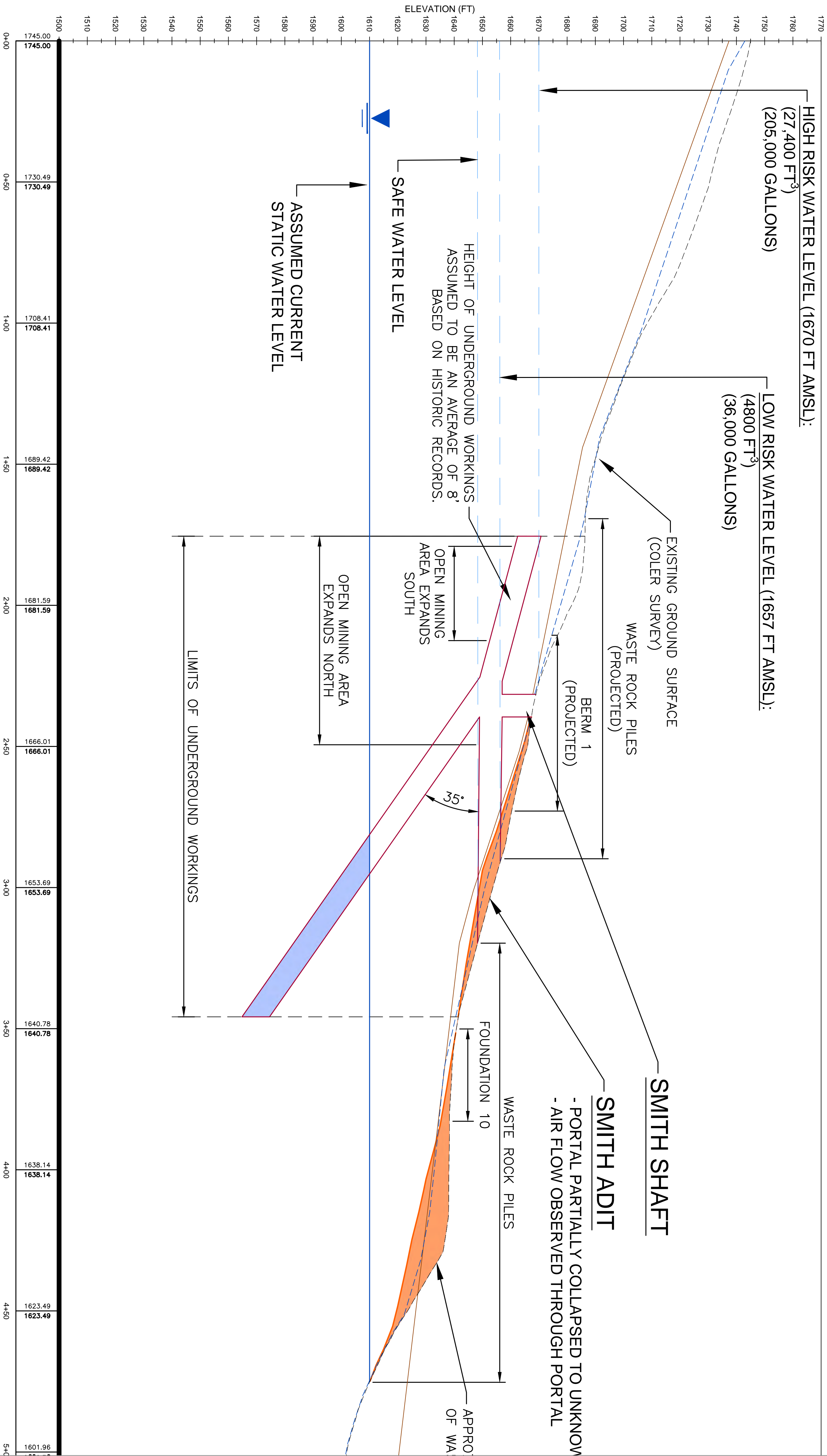
REPORT	PIKE HILL FMEA	CLIENT	NOBIS ENGINEERING INC.	ISSUED DATE	Jan 2018
PROVIDED BY	SLR INTERNATIONAL CORPORATION Consulting Engineers & Scientists	PROJECT	PIKE HILL MINES FMEA	PROJECT No.	117.00975.00003
TITLE PLAN VIEW OF UNDERGROUND WORKINGS UNION MINE				FIGURE No.	3-2

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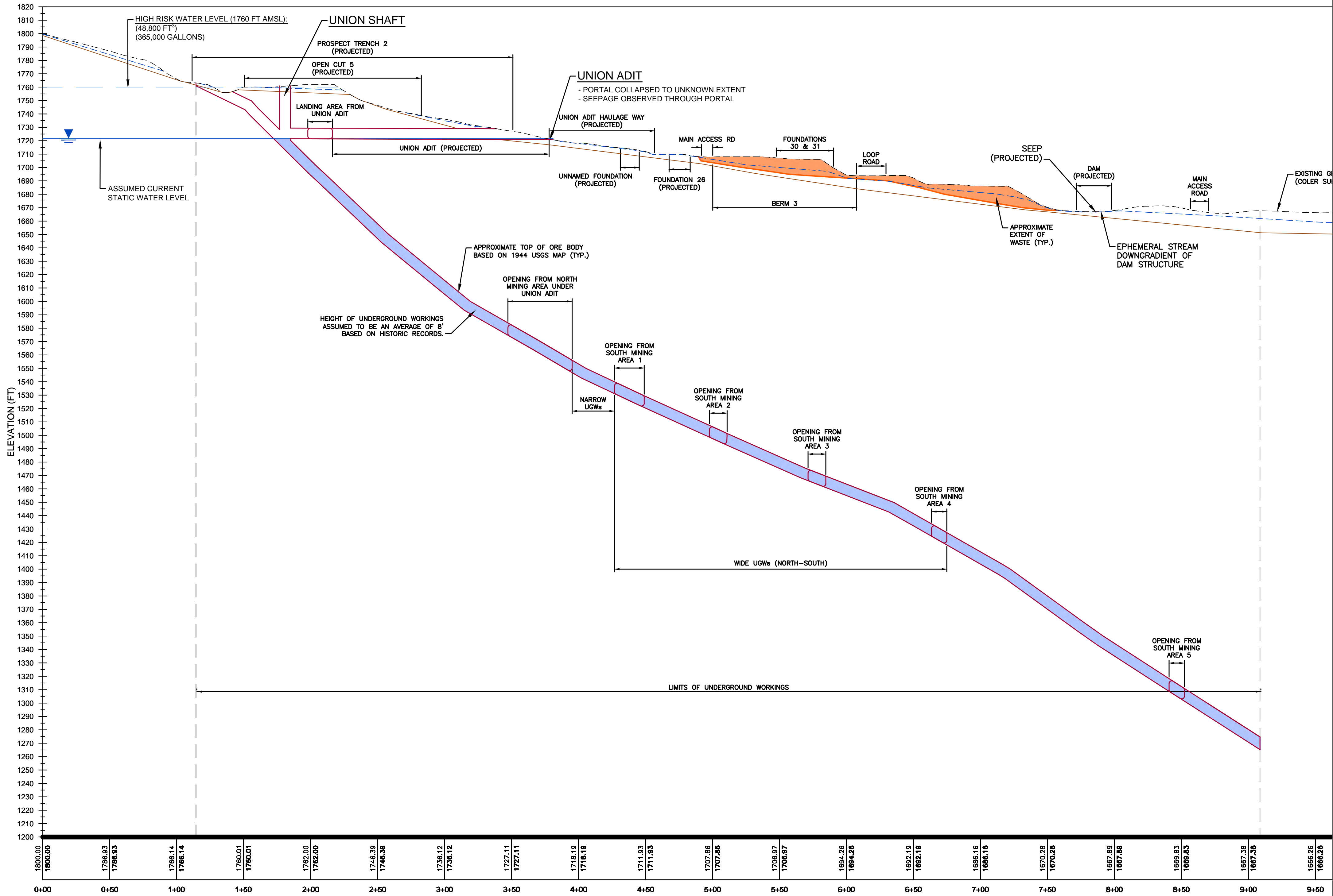


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SLR INTERNATIONAL CORPORATION Consulting Engineers & Scientists		TITLE	PLAN VIEW OF UNDERGROUND WORKINGS EUREKA MINE	FIGURE No.	3-3



- NOTES:
1. EXISTING GROUND SURFACE BASED ON GROUND SURVEY AND AERIAL MAPPING PERFORMED BY COLER & COLANTONIO AND MINUTEMAN MAPPING, RESPECTIVELY, IN SPRING 2006.
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 3. CROSS SECTION FROM NOBIS 2017

- LEGEND
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 - INFERRED OVERBURDEN GROUNDWATER LEVEL
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 - WASTE ROCK PILE



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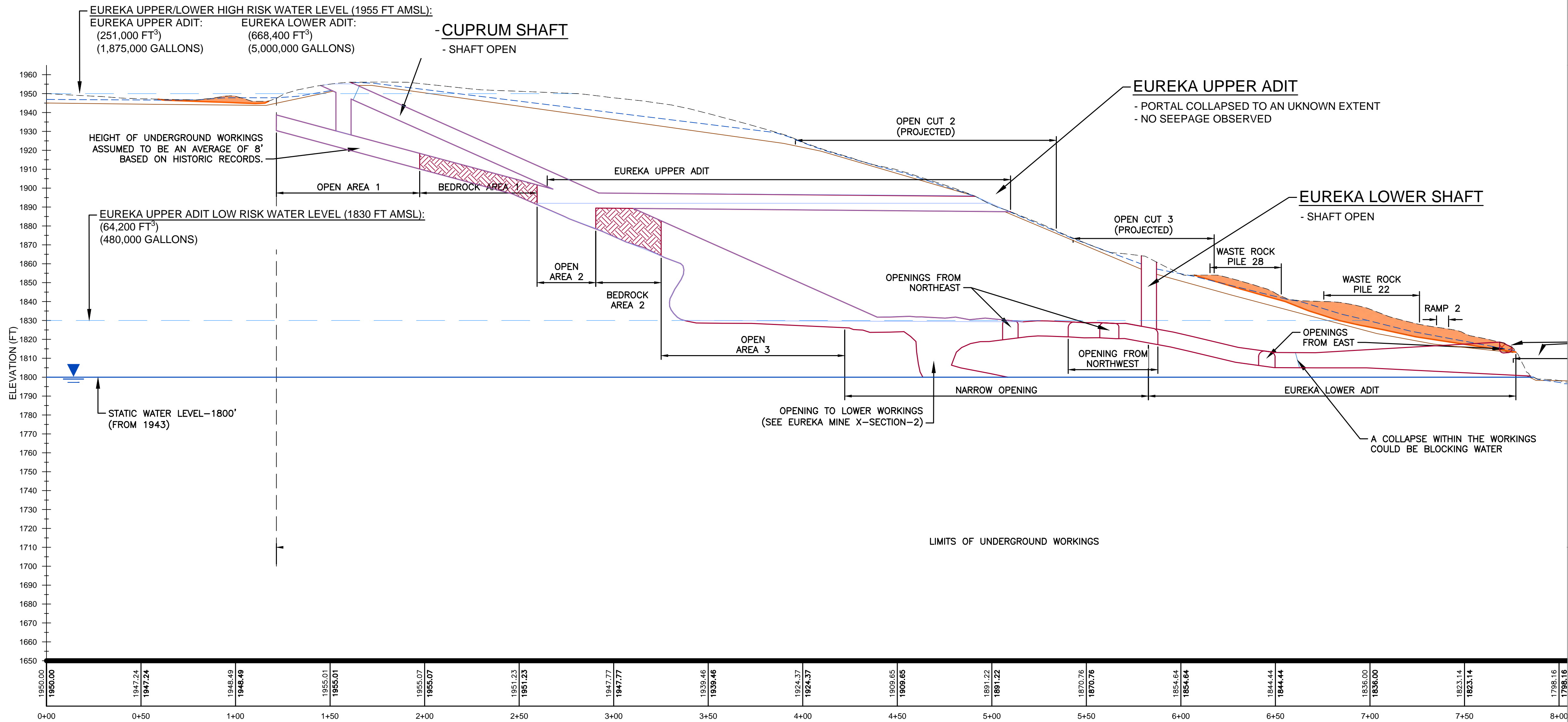
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REPORT

PIKE HILL FMEA

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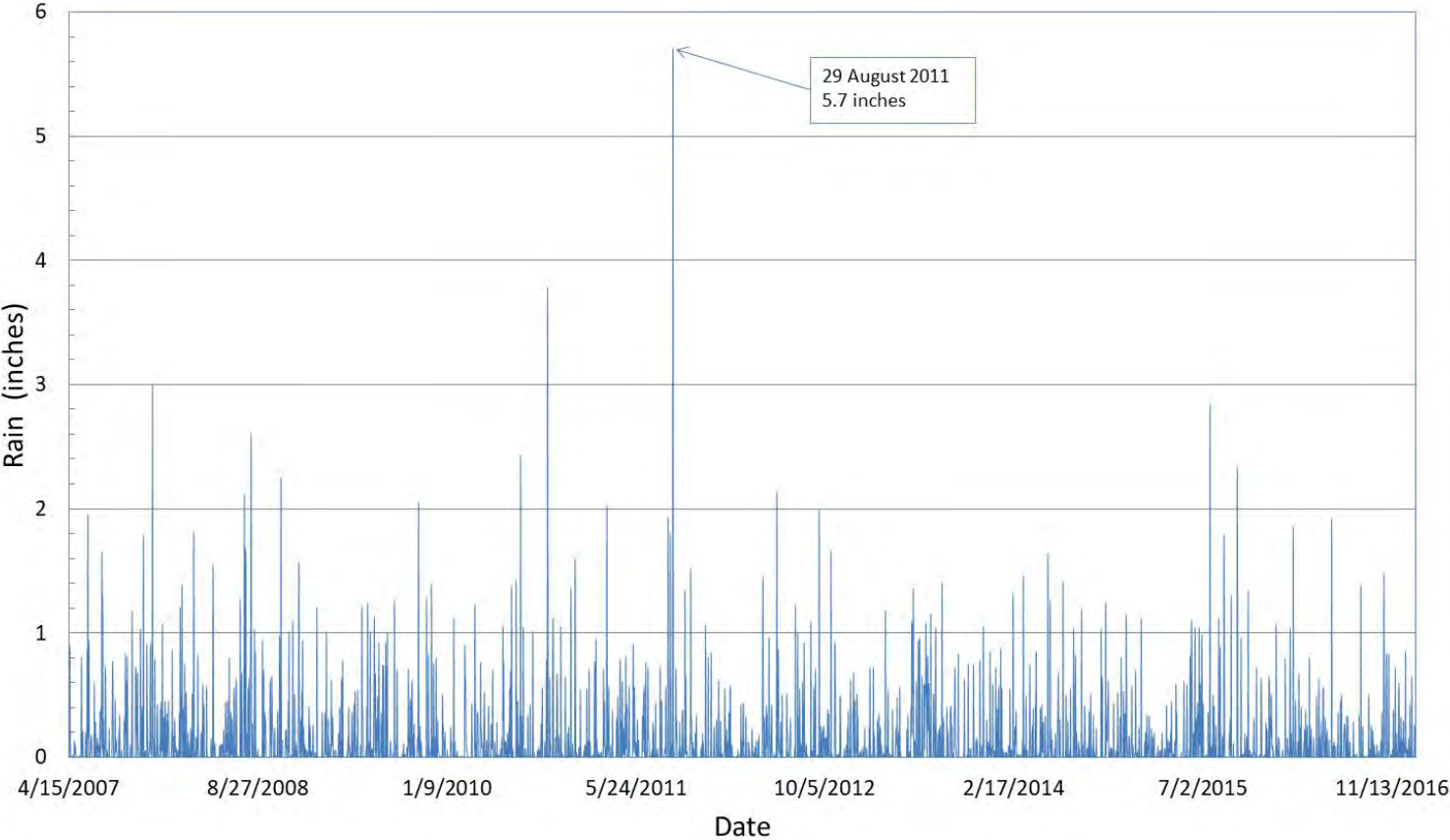
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Figure 4-1: Pike Hill FMEA Risk Characterization Matrix

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300				
	Level 2 100				
	Level 1 30				
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

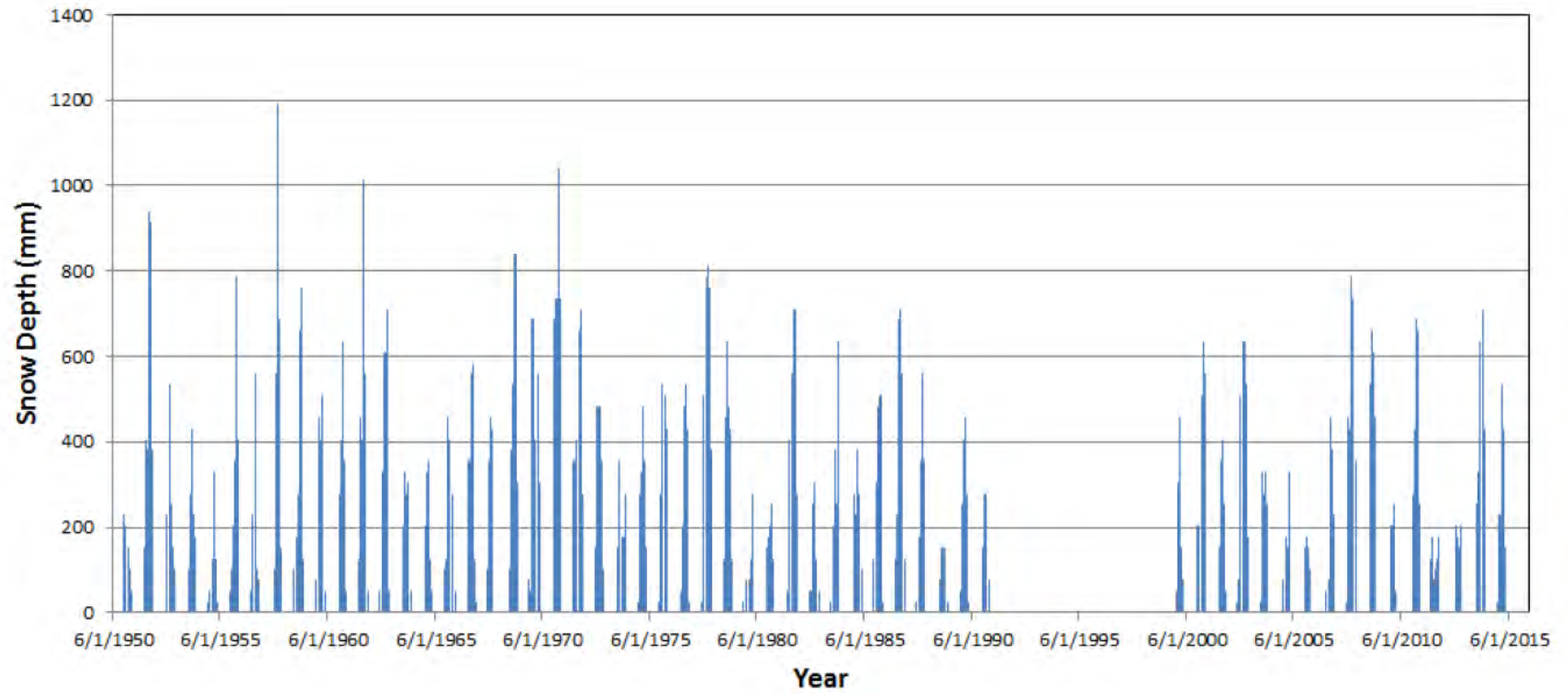
Figure 5-1: Precipitation between 2007 and 2017 at Corinth Weather Station near Pike Hill Mine

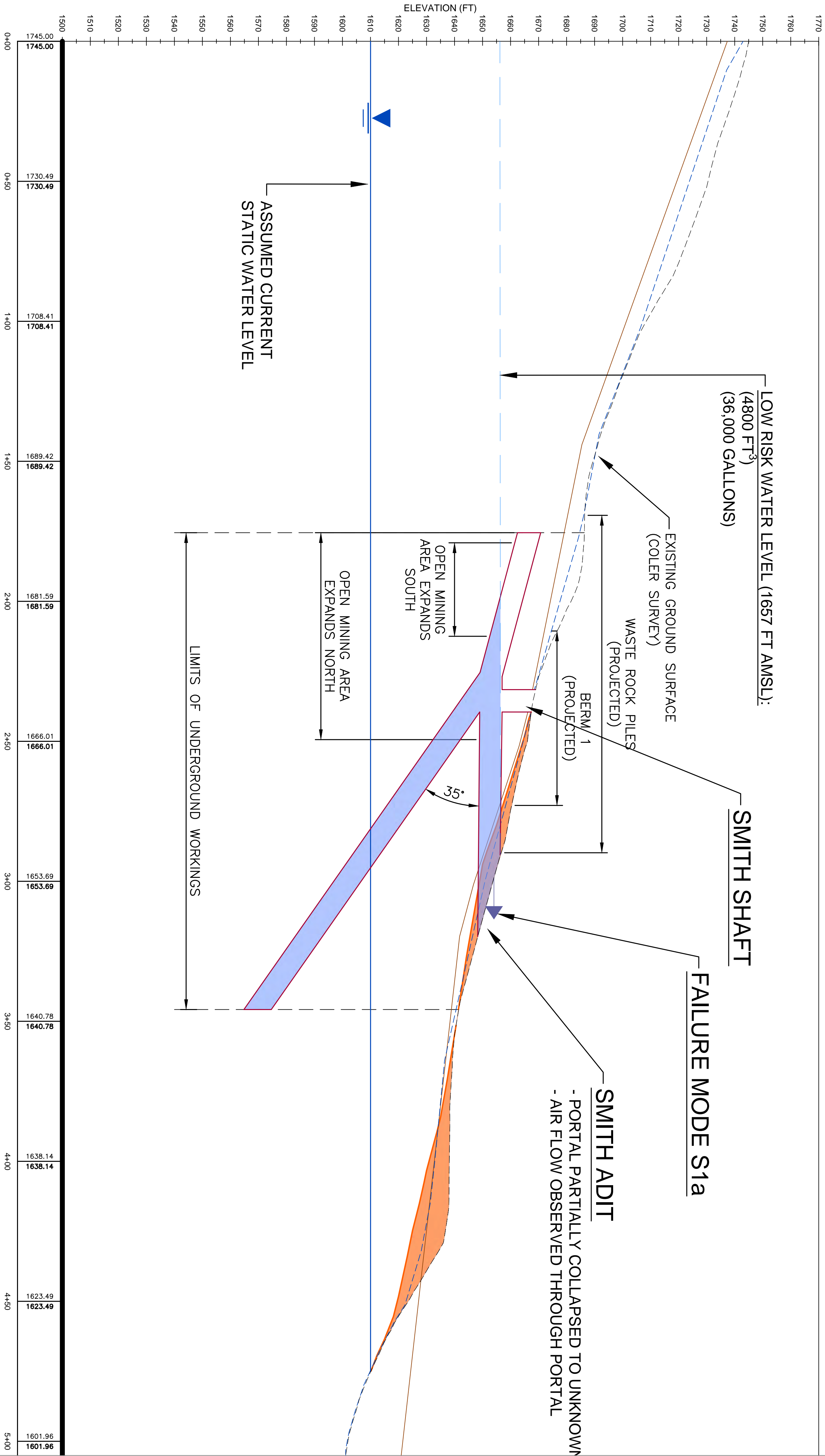


The graph illustrates the relationship between rain intensity (inches) and duration (minutes) for different return periods. The y-axis represents Rain (inches) from 0 to 14, and the x-axis represents Time in Minutes on a logarithmic scale from 1 to 100,000. A vertical red line at 1,440 minutes (24 hours) is marked with a red dot and labeled '24hrs=1,440 min.'.

Time (min)	1 yr	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	200 yr	500 yr
1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
100	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1,000	1.5	1.8	2.2	2.5	3.0	3.5	4.0	4.5	5.0
1,440	1.8	2.2	2.8	3.2	3.8	4.5	5.2	6.0	7.0
10,000	3.0	3.8	4.8	5.5	7.0	8.5	10.0	11.5	13.0

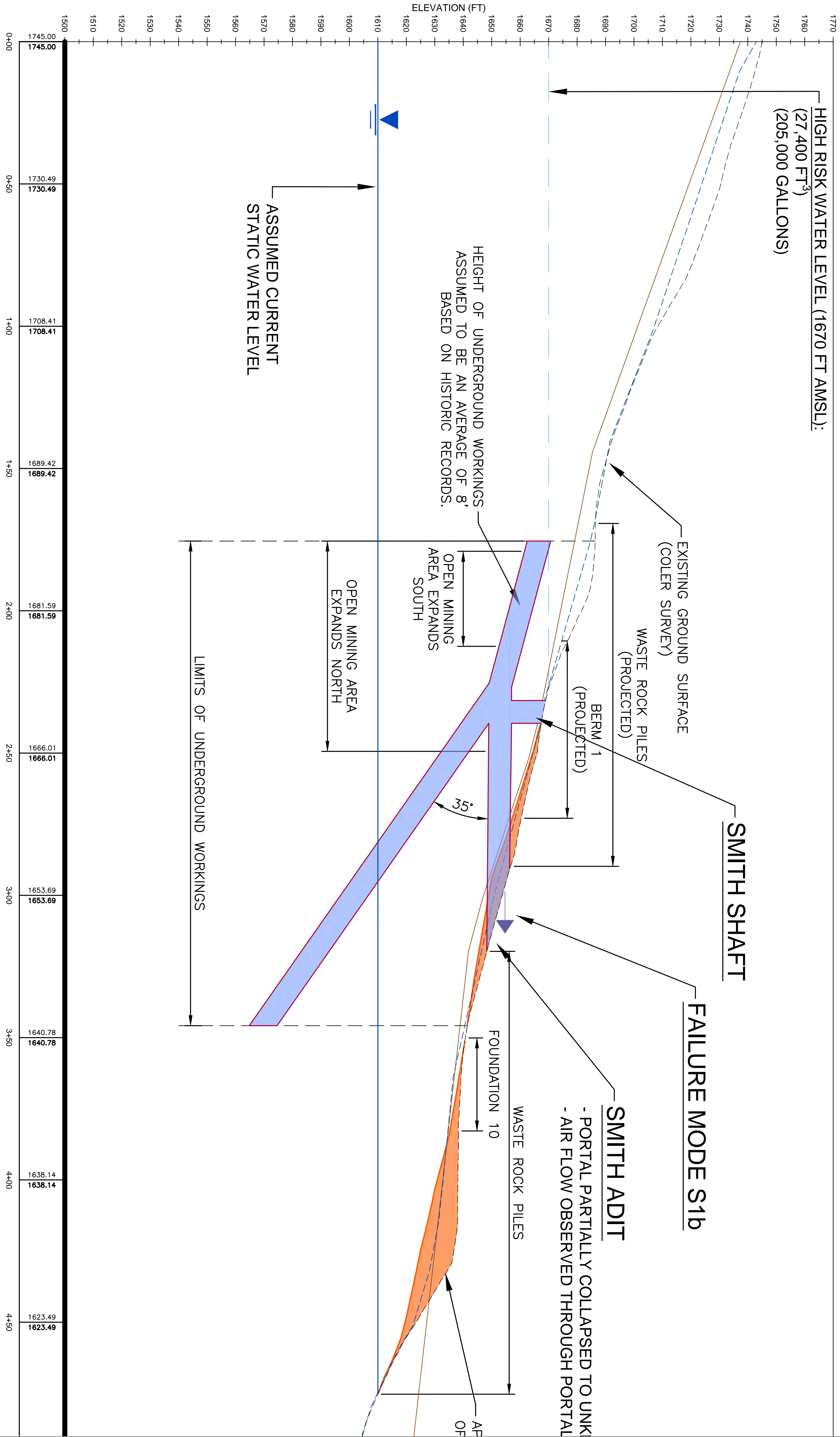
Figure 5-3: Snow Depth at Union Village Station (1950-2015)





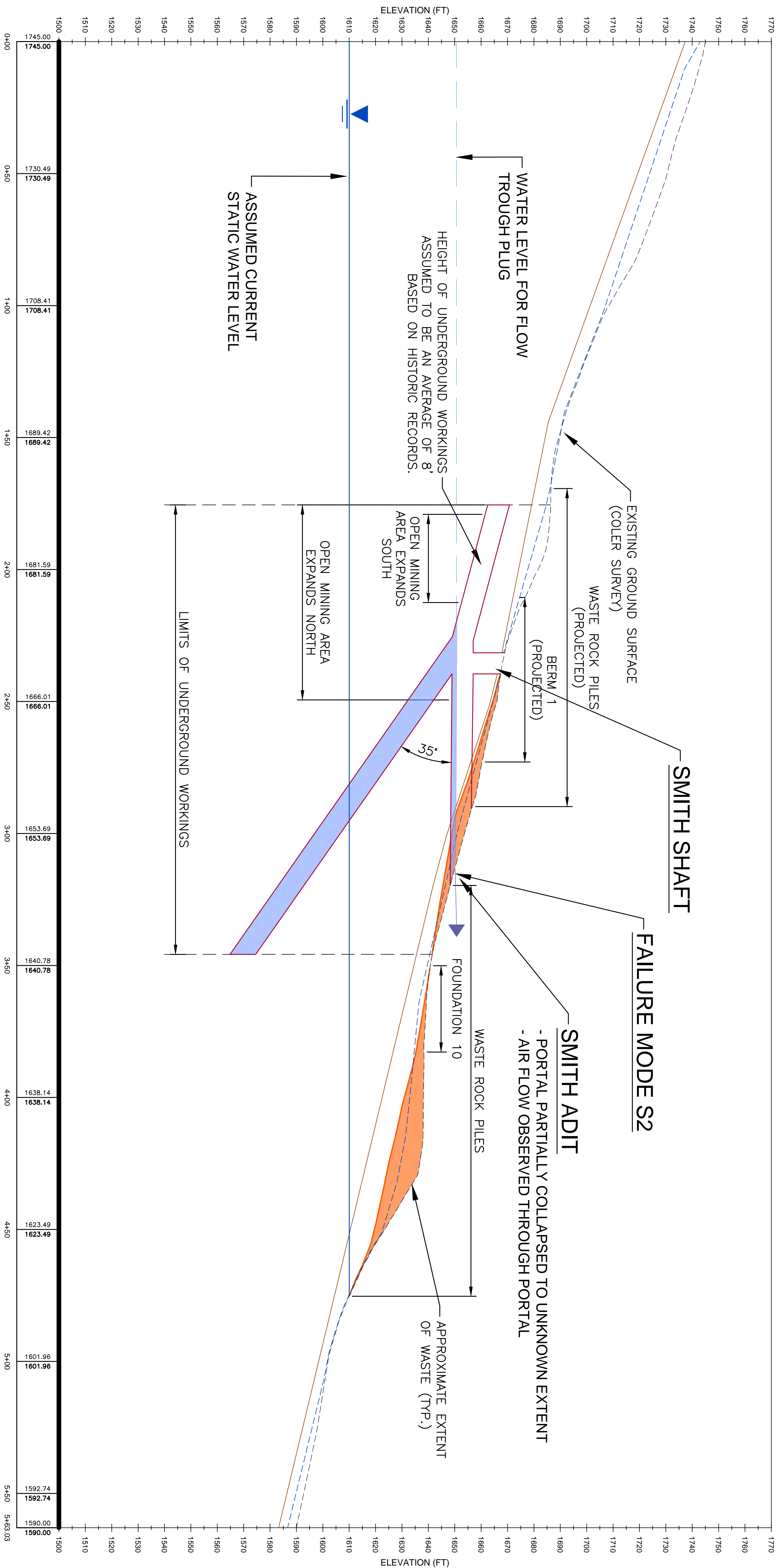
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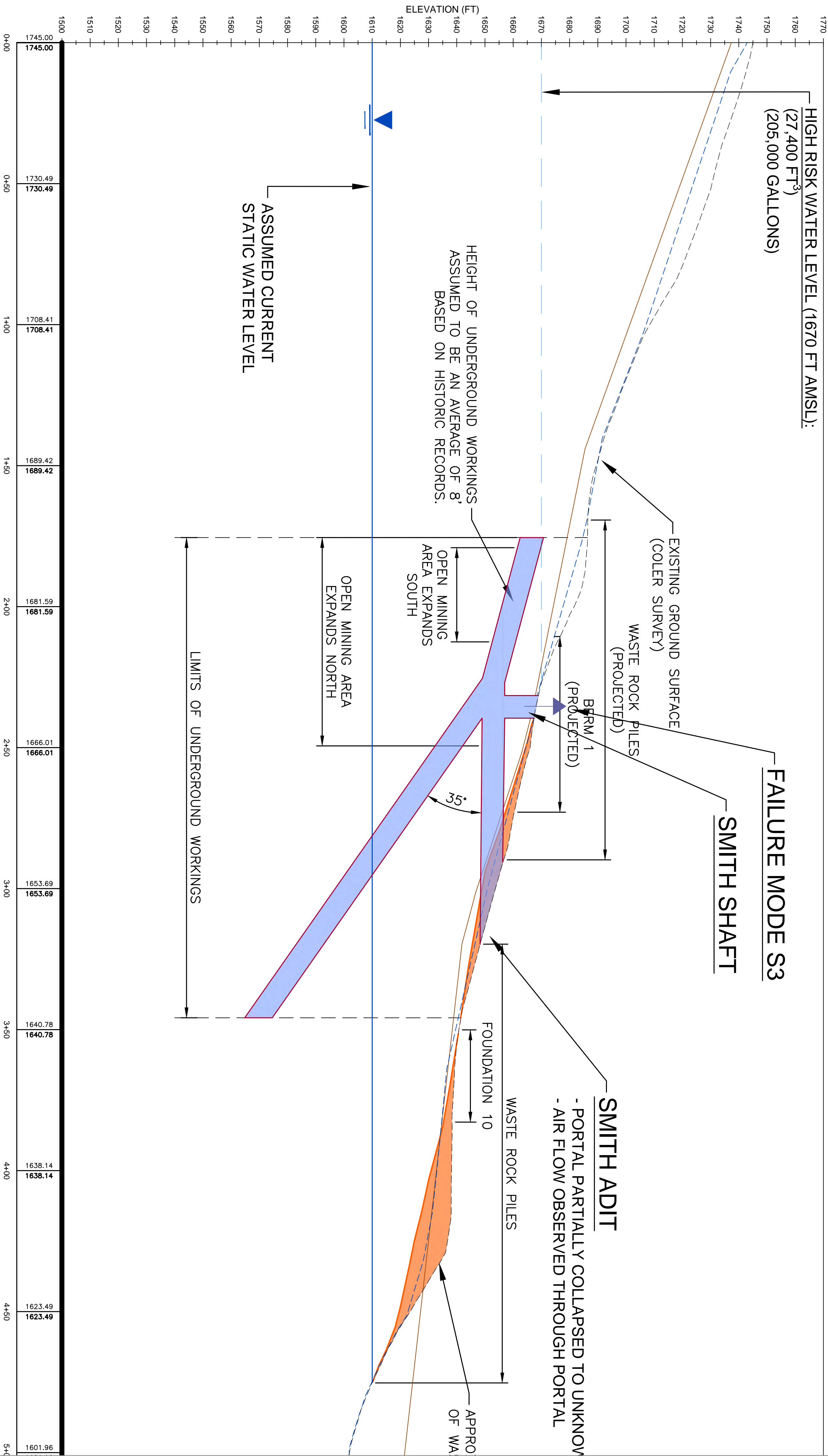
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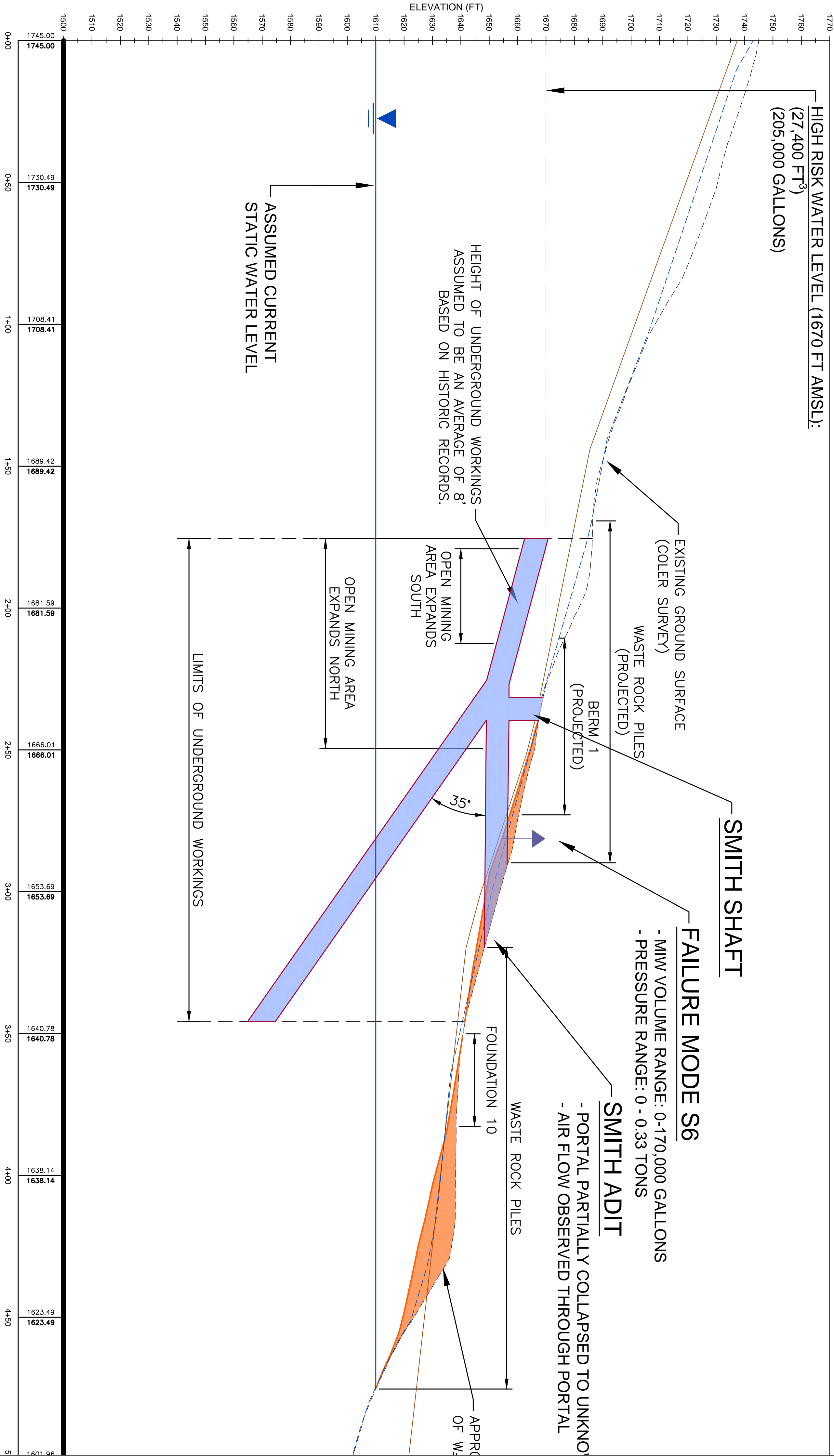
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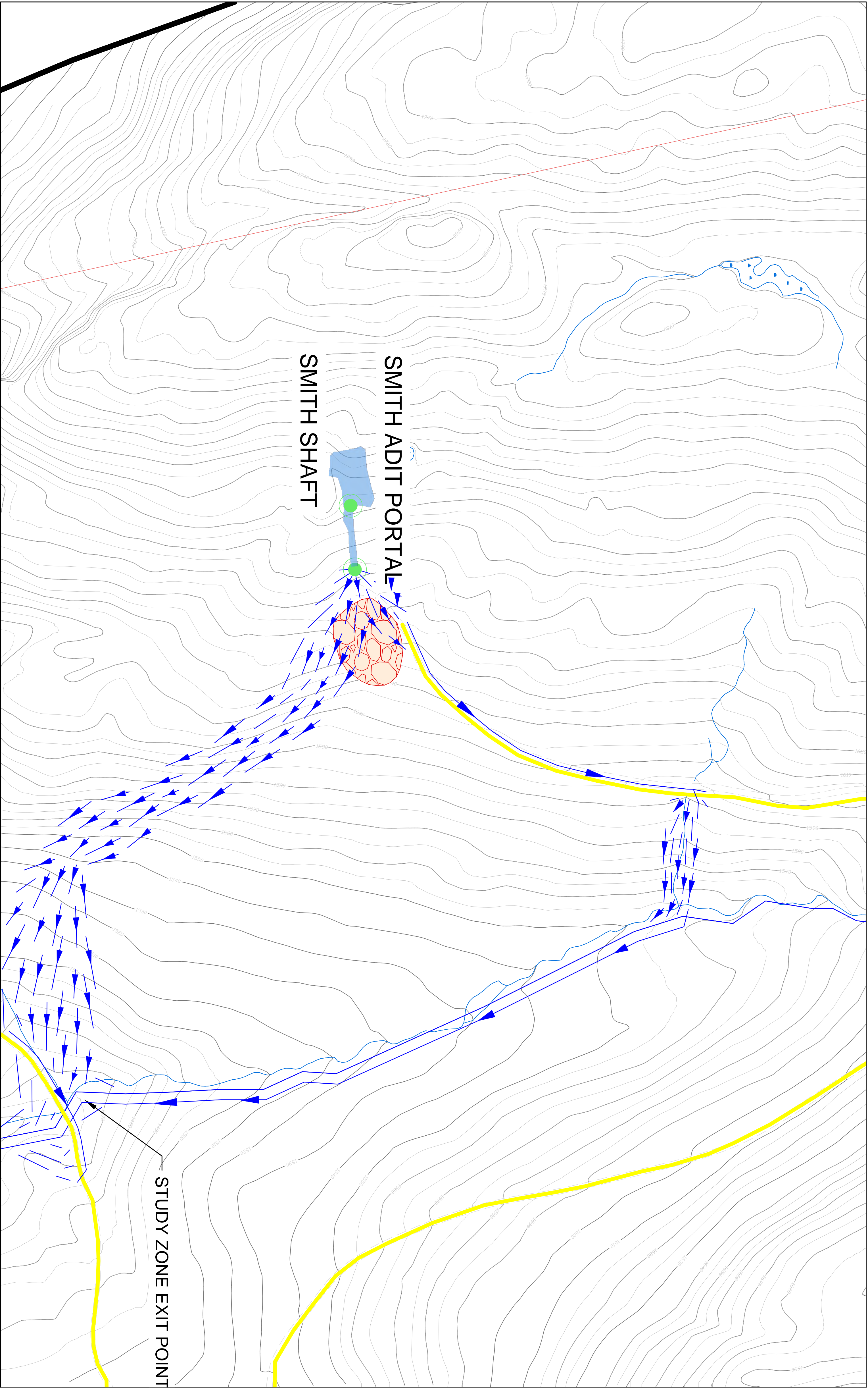
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LEGEND

---	EXISTING GROUND SURFACE	---	EXTENTS OF UNDERGROUND WORKINGS
---	INFERRED OVERBURDEN GROUNDWATER LEVEL	---	POTENTIAL FLOODED UNDERGROUND WORKINGS
---	INFERRED STATIC GROUNDWATER LEVEL	---	UNMINED BEDROCK AREA
---	LOW RISK WATER LEVEL	---	WASTE MATERIAL
---	HIGH RISK WATER LEVEL	---	FAILURE MODE EXIT PATH
---	INFERRED BEDROCK SURFACE	---	

APPROXIMATE LOCATION OF UNDERGROUND WORKINGS

---	WASTE ROCK PILE
-----	-----------------

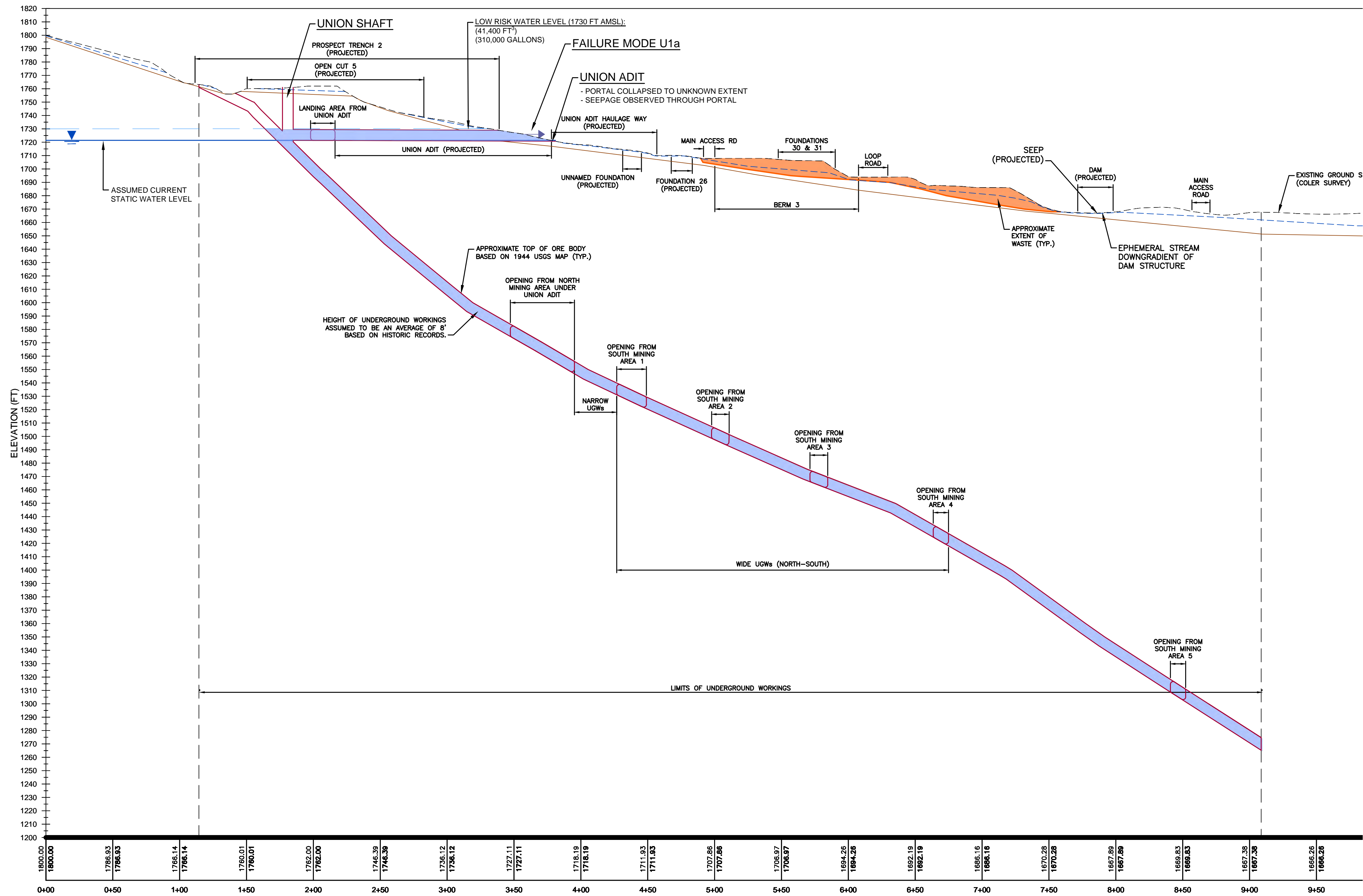


LEGEND:

- = WASTE ROCK PILE
- = ROAD
- = FAILURE MODE RELEASE POINT
- = FAILURE MODE DISCHARGE PATH
- = EPHEMERAL CREEK / SURFACE WATER
- = EXISTING CHANNEL
- = EXISTING STRUCTURE

FAILURE MODE CHARACTERISTICS:

- FAILURE MODE S1A:
 - DISCHARGE VOLUME = 36,000 GALLONS
 - HEAD = 8 FT
- FAILURE MODE S1B:
 - DISCHARGE VOLUME = 205,000 GALLONS
 - HEAD = 20 FT



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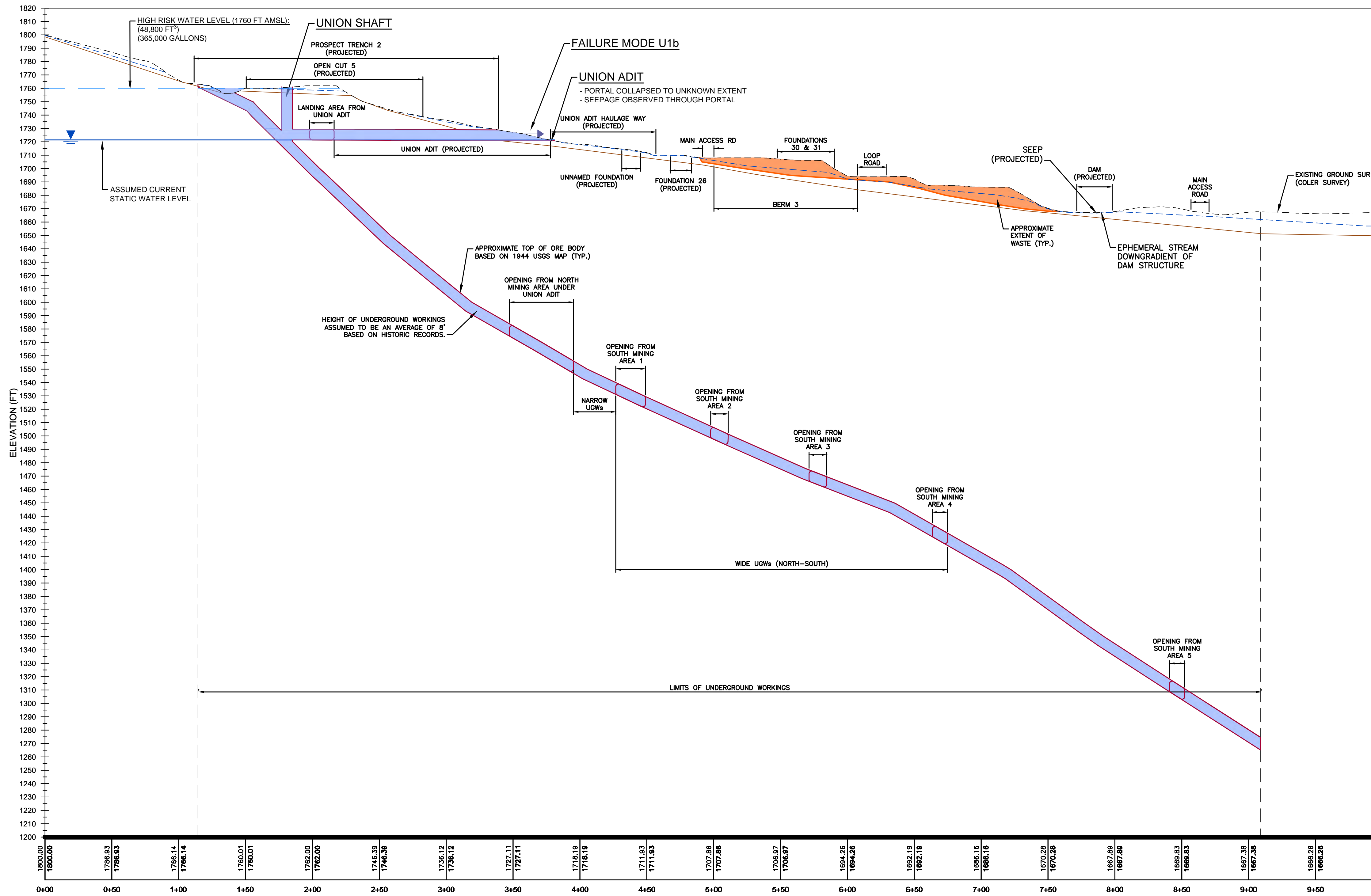
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LEGEND

- EXISTING GROUND SURFACE
- INFERRED OVERBURDEN GROUNDWATER LEVEL
- INFERRED STATIC GROUNDWATER LEVEL
- LOW RISK WATER LEVEL
- HIGH RISK WATER LEVEL
- INFERRED BEDROCK SURFACE
- EXTENTS OF UNDERGROUND WORKINGS
- POTENTIAL FLOODED UNDERGROUND WORKINGS
- UNMINED BEDROCK AREA
- WASTE MATERIAL
- FAILURE MODE EXIT PATH
- APPROXIMATE LOCATION OF UNDERGROUND WORKINGS
- WASTE ROCK PILE

REPORT

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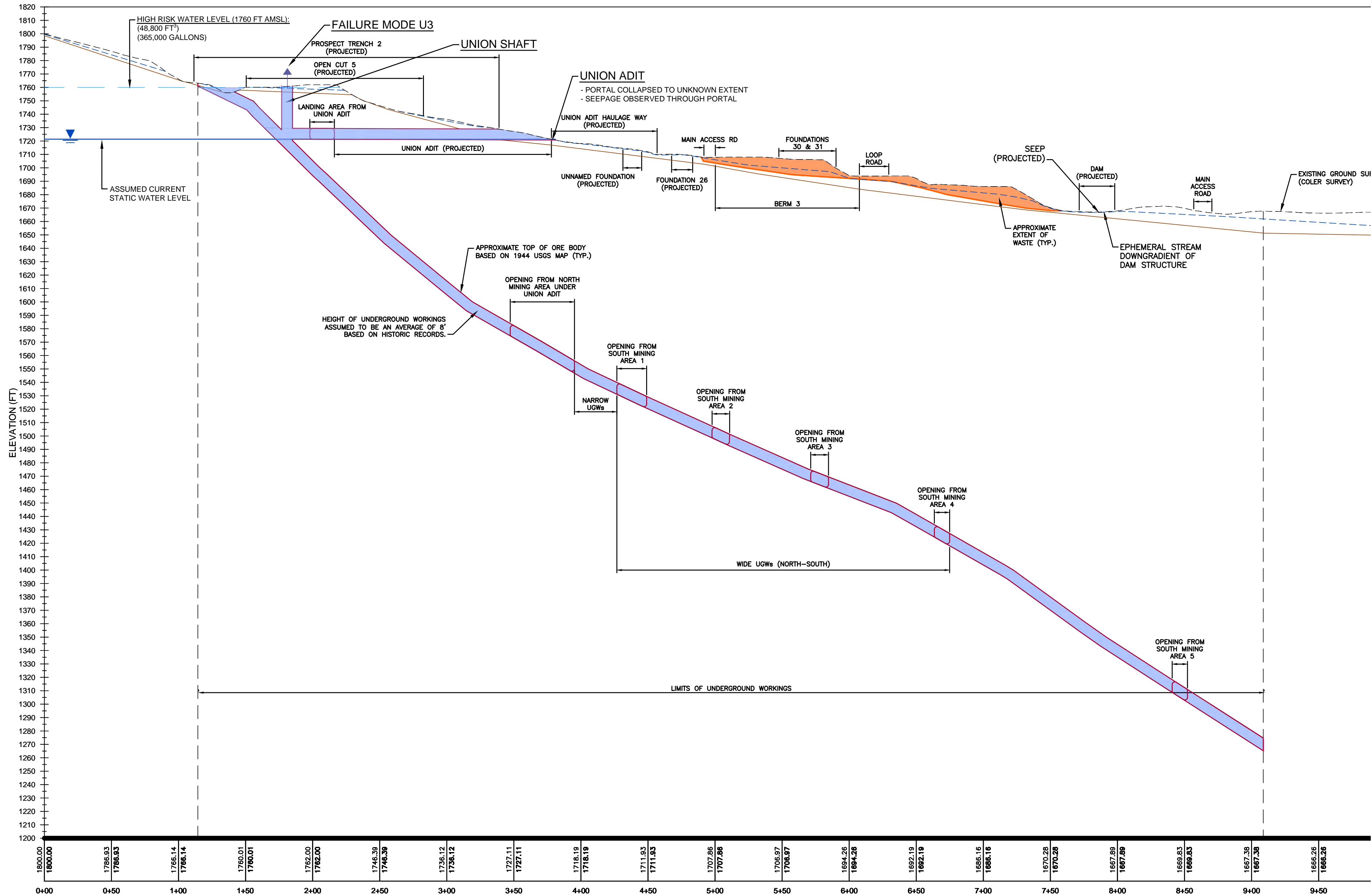
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Legend for Figure 10: Cross-section of the proposed underground workings.

- EXISTING GROUND SURFACE
- INFERRED OVERBURDEN GROUNDWATER LEVEL
- INFERRED STATIC GROUNDWATER LEVEL
- LOW RISK WATER LEVEL
- HIGH RISK WATER LEVEL
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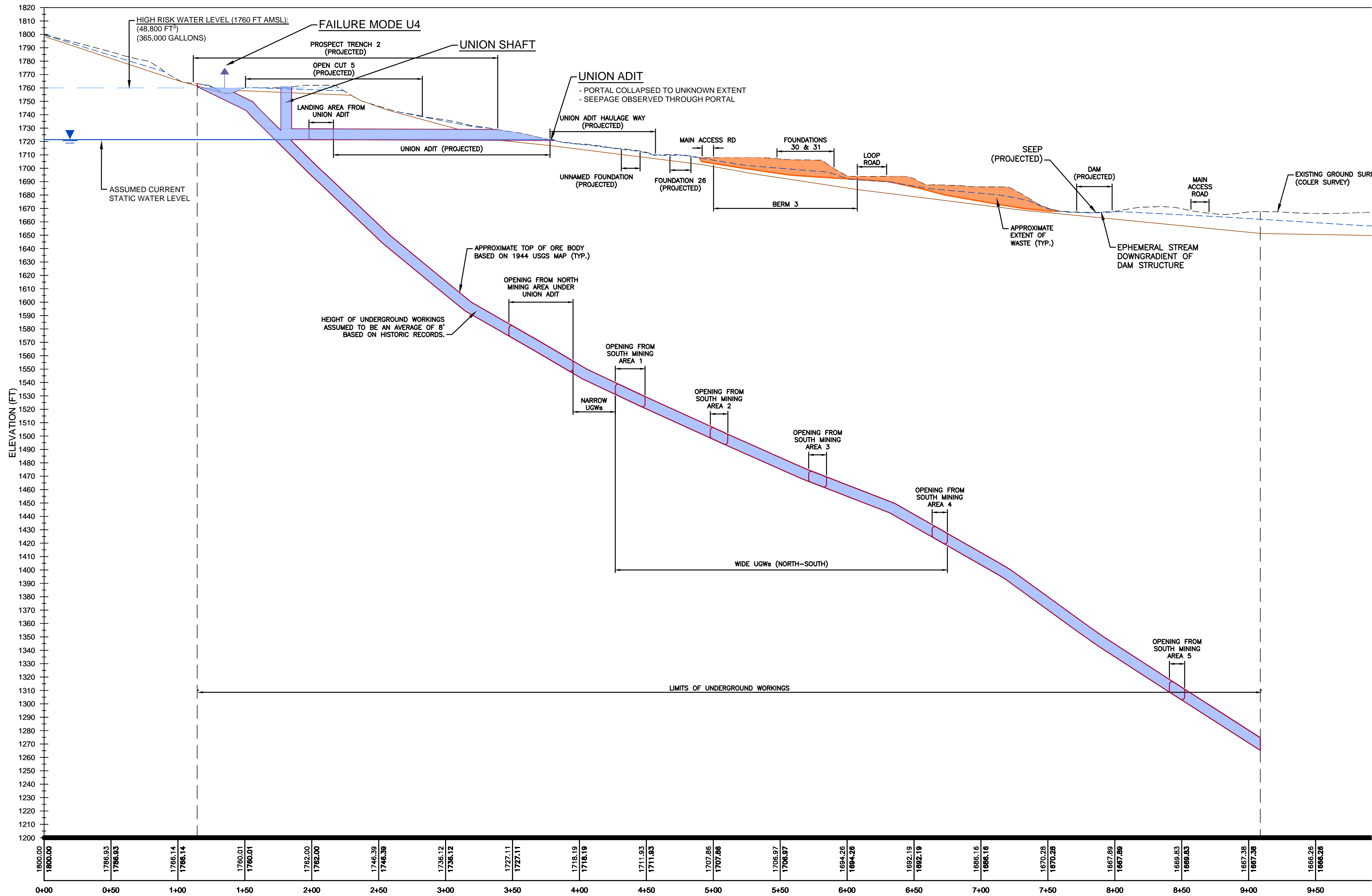
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LEGEND

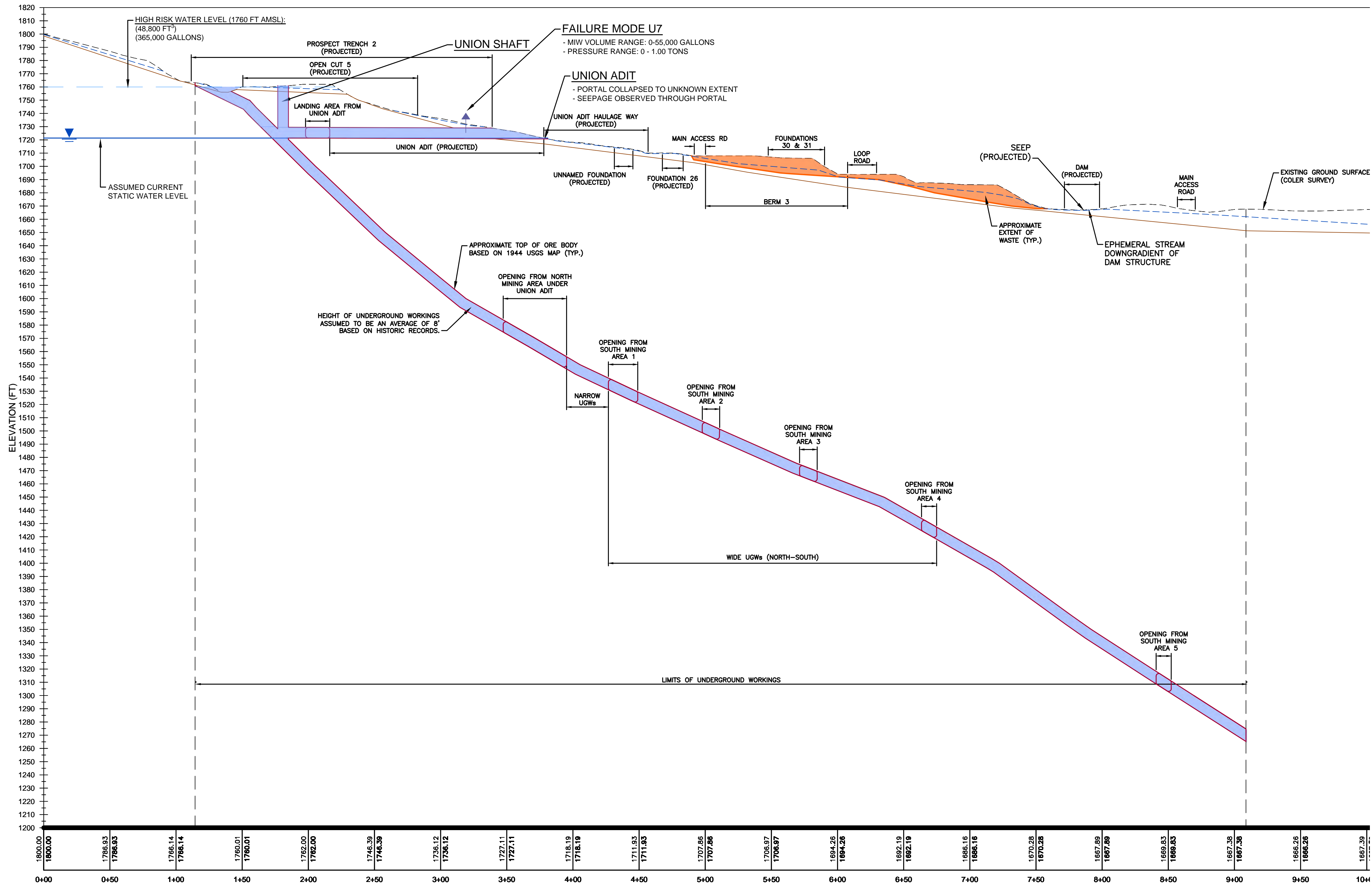
- EXISTING GROUND SURFACE
- INFERRED OVERBURDEN GROUNDWATER LEVEL
- INFERRED STATIC GROUNDWATER LEVEL
- LOW RISK WATER LEVEL
- HIGH RISK WATER LEVEL
- INFERRED BEDROCK SURFACE
- EXTENTS OF UNDERGROUND WORKINGS
- POTENTIAL FLOODED UNDERGROUND WORKINGS
- UNMINED BEDROCK AREA
- WASTE MATERIAL
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- WASTE ROCK PILE

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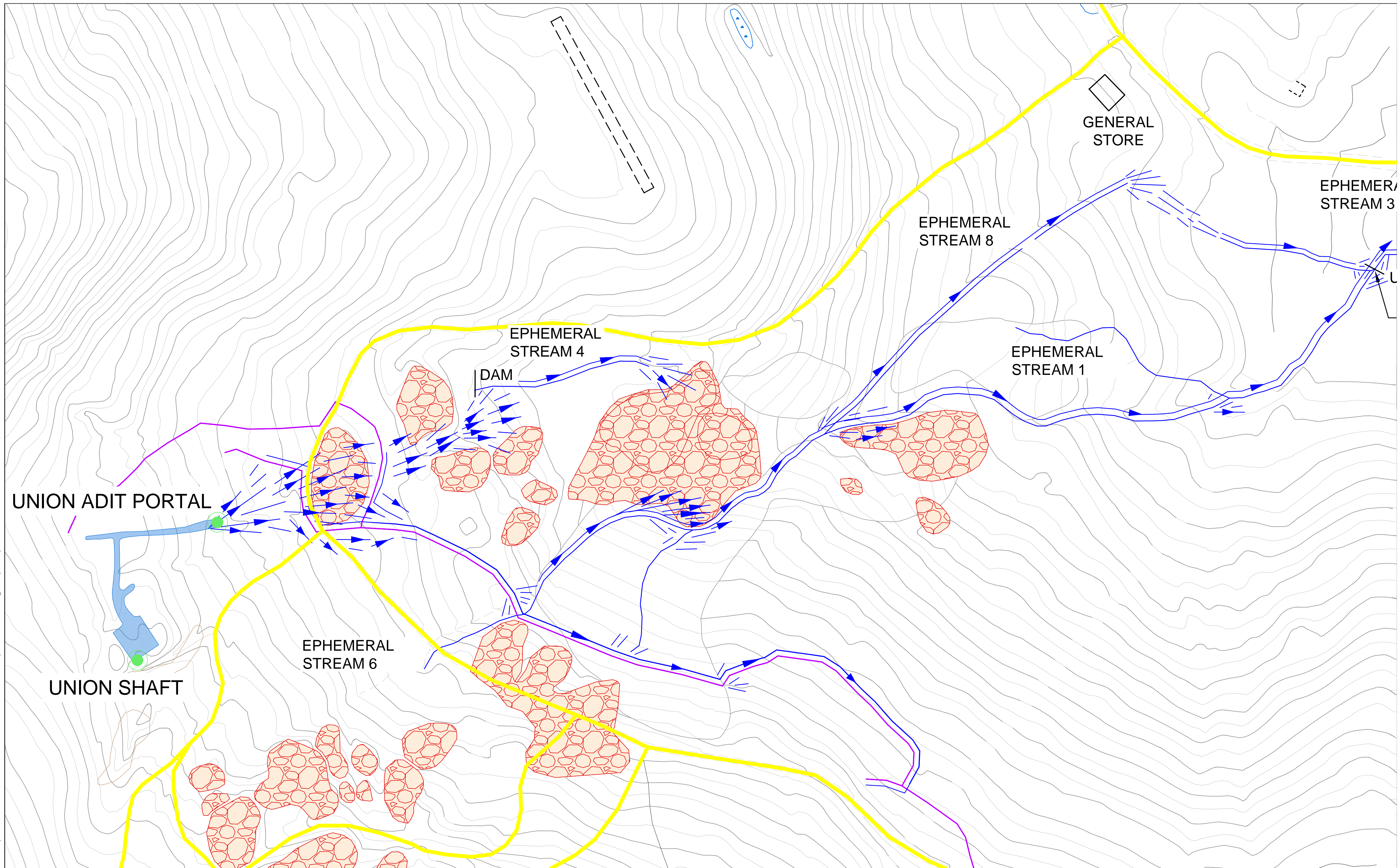
LEGEND

- EXISTING GROUND SURFACE
- INFERRED OVERBURDEN GROUNDWATER LEVEL
- INFERRED STATIC GROUNDWATER LEVEL
- LOW RISK WATER LEVEL
- HIGH RISK WATER LEVEL
- INFERRED BEDROCK SURFACE

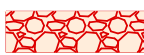






- EXTENTS OF UNDERGROUND WORKINGS
- POTENTIAL FLOODED UNDERGROUND WORKINGS
- UNMINED BEDROCK AREA
- WASTE MATERIAL
- FAILURE MODE EXIT PATH

- APPROXIMATE LOCATION OF UNDERGROUND WORKINGS
- WASTE ROCK PILE

N:\Irvine\CAD\117.00975 PIKE HILL\4. SLR CAD Files-March 2017\FIGURE.dwg-2/23/2018 3:10 PM

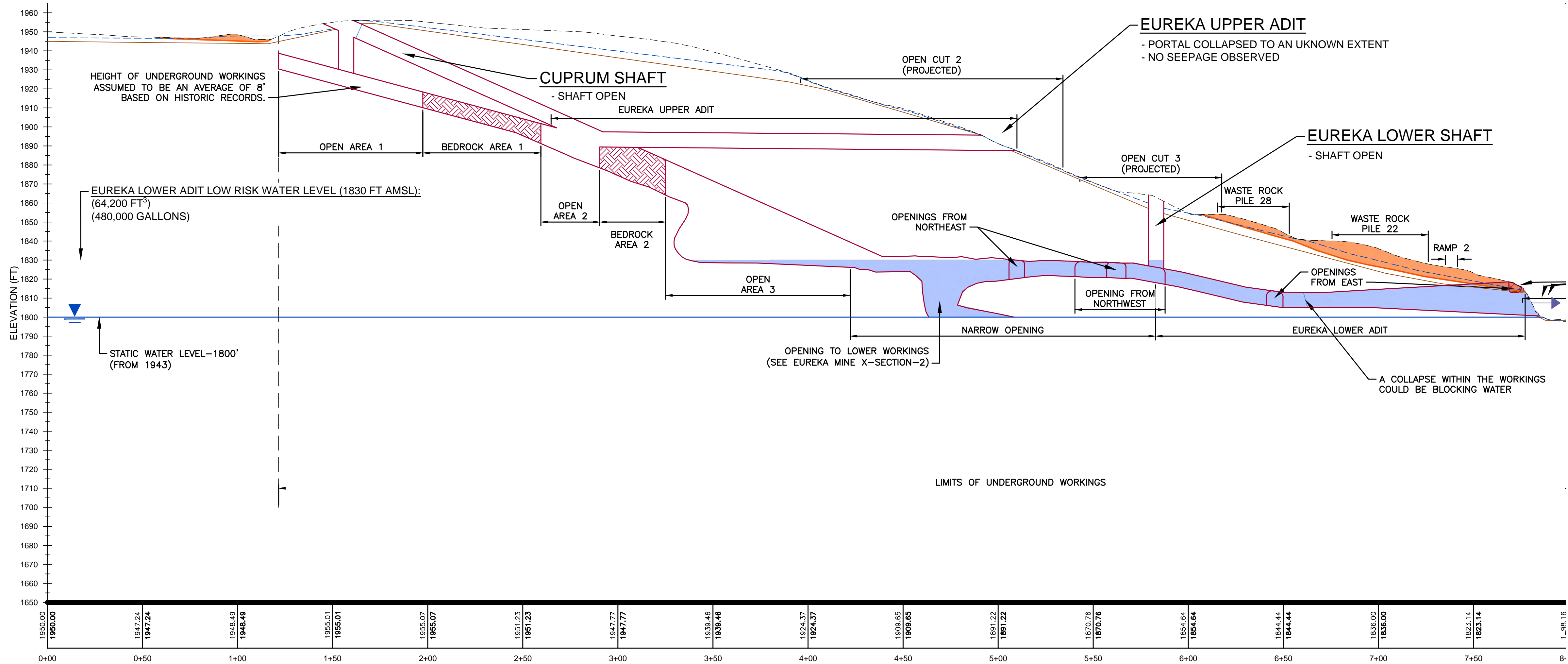


LEGEND:

-  = WASTE ROCK PILE
-  = ROAD
-  = FAILURE MODE RELEASE POINT
-  = FAILURE MODE DISCHARGE PATH
-  = EPHEMERAL CREEK / SURFACE WATER
-  = EXISTING CHANNEL
-  = EXISTING STRUCTURE

FAILURE MODE CHARACTERISTICS:

- FAILURE MODE S1A:
- DISCHARGE VOLUME = 36,000 GALLONS
 - HEAD = 8 FT
- FAILURE MODE S1B:
- DISCHARGE VOLUME = 205,000 GALLONS
 - HEAD = 20 FT



NOTES:

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LEGEND

- EXISTING GROUND SURFACE
- INFERRED OVERBURDEN GROUNDWATER LEVEL
- INFERRED STATIC GROUNDWATER LEVEL
- LOW RISK WATER LEVEL
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- UNMINED BEDROCK AREA
- WASTE MATERIAL
- FAILURE MODE EXIT PATH

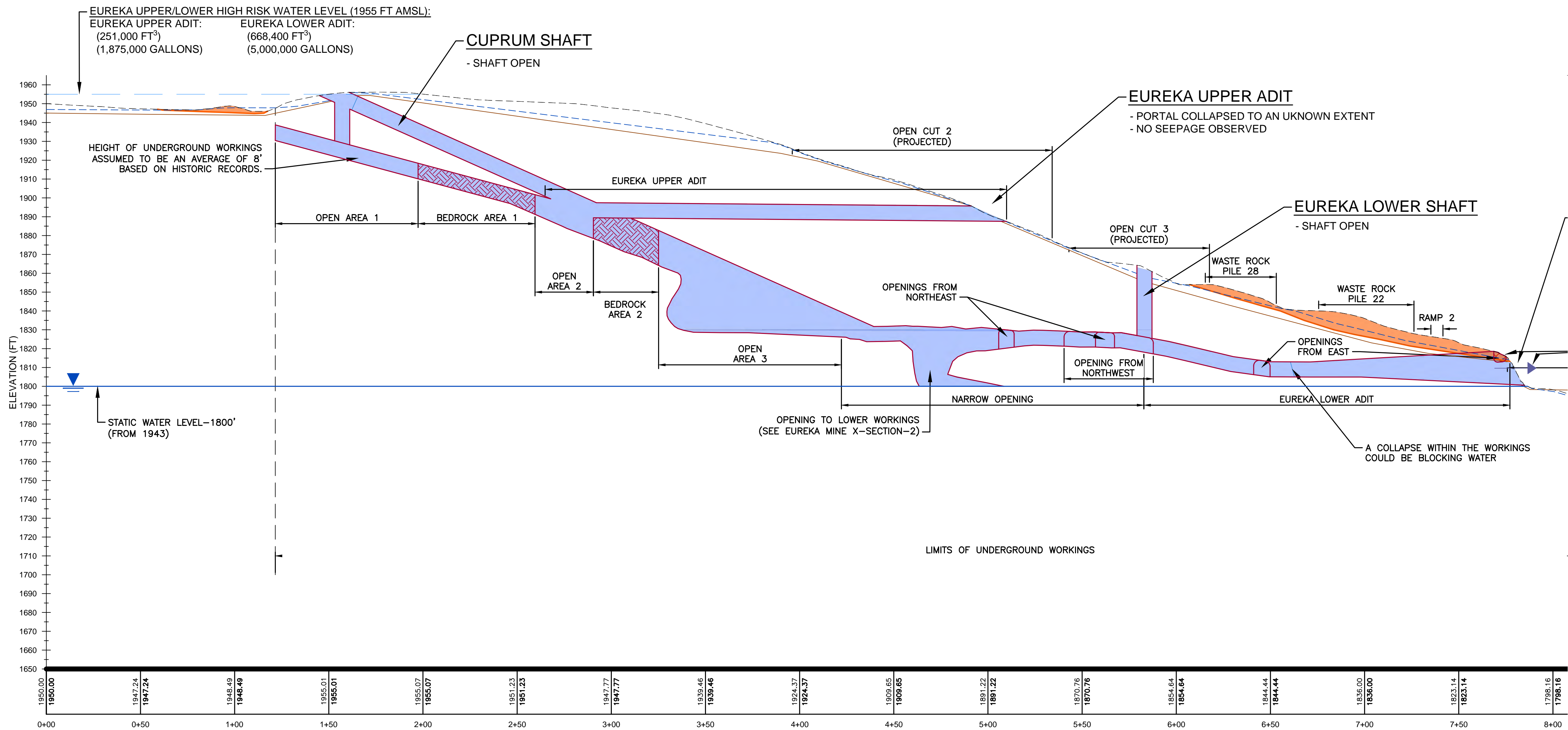
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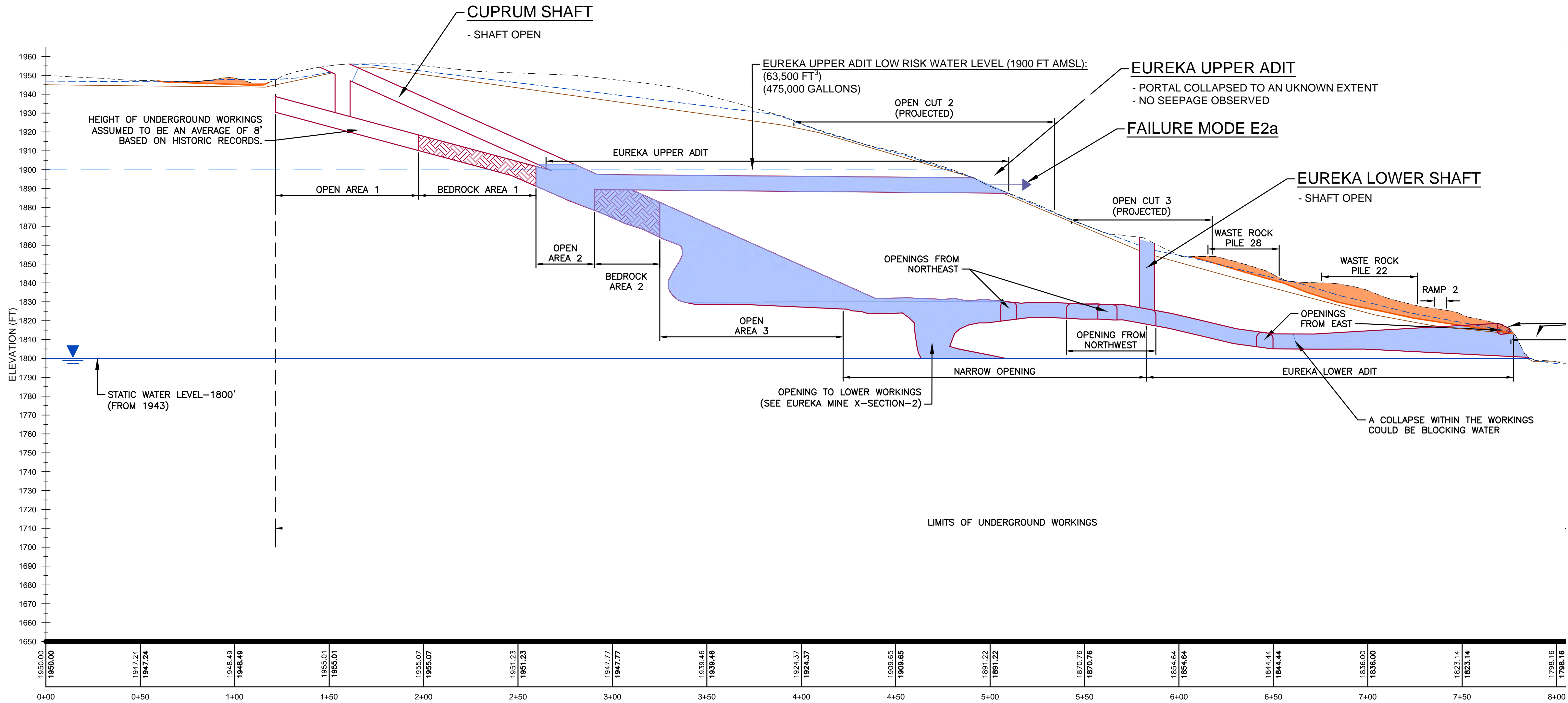
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LEGEND

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- INFERRED OVERBURDEN GROUNDWATER LEVEL
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- LOW RISK WATER LEVEL
- HIGH RISK WATER LEVEL
- INFERRED BEDROCK SURFACE

- EXTENTS OF UNDERGROUND WORKINGS
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- WASTE MATERIAL
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- APPROXIMATE UNDERGROUND
- WASTE ROCK PILE



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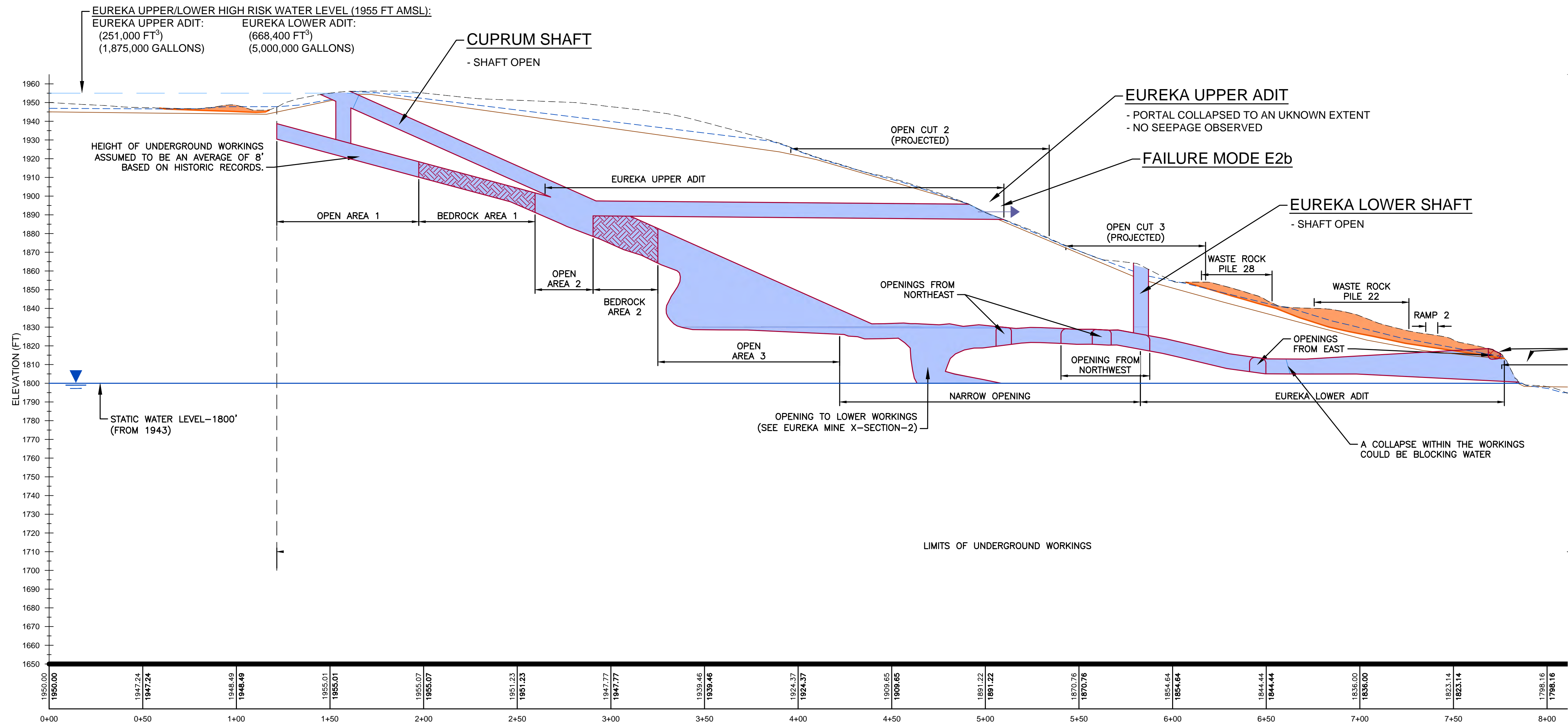
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N:\Irvine\CAD\117.00975 PIKE HILL\4. SLR CAD Files-March 2017\FIGURE.dwg-2/23/2018 3:10 PM



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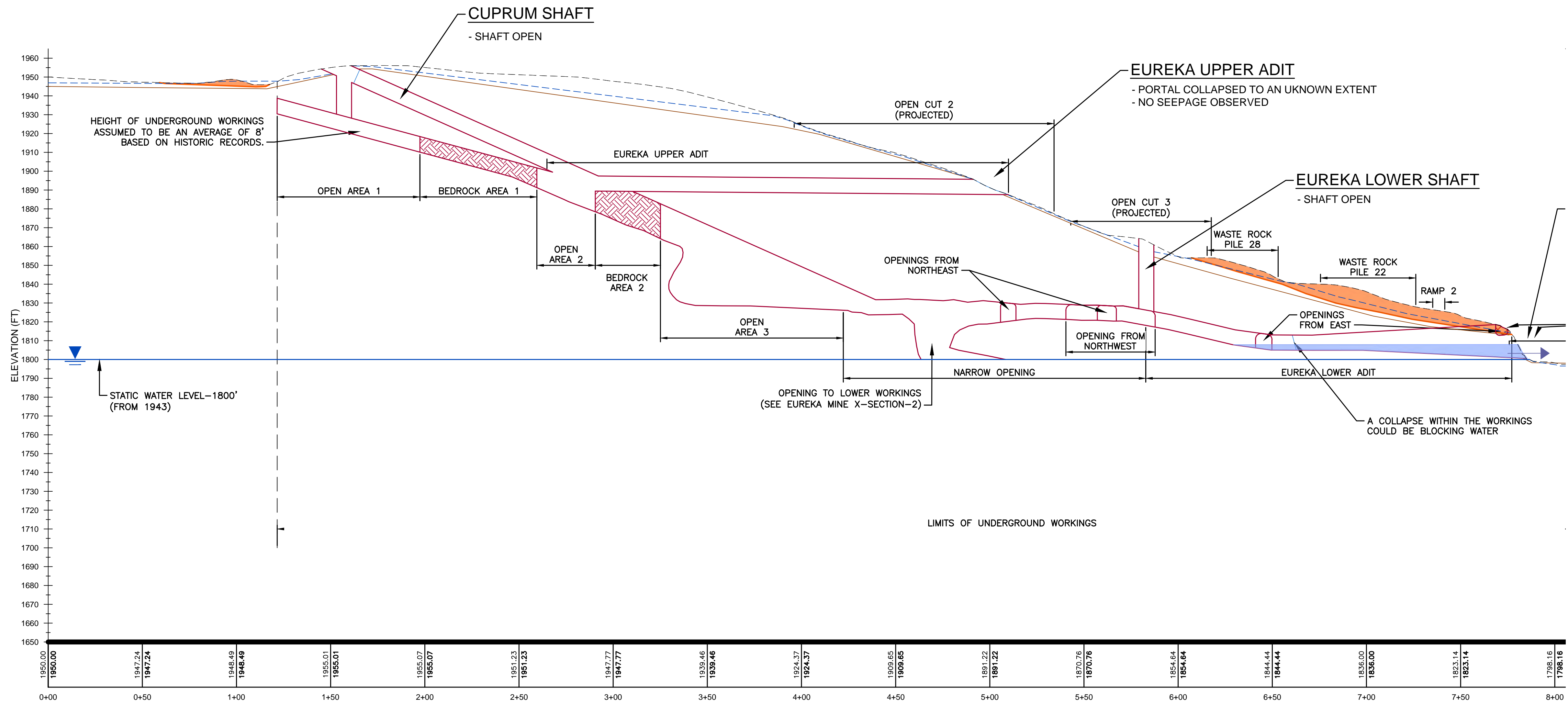
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- APPROXIMATE UNDERGROUND WORKINGS
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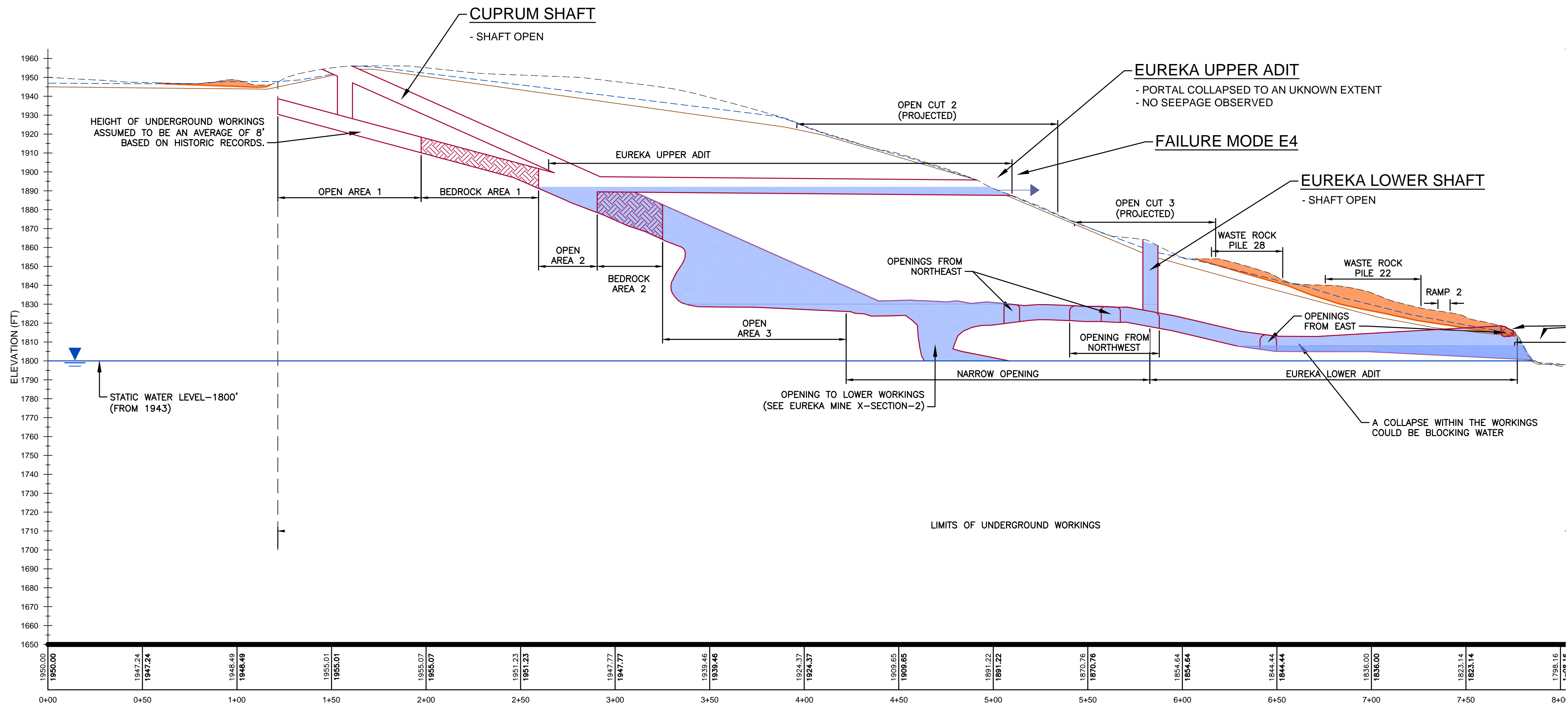
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- WASTE MATERIAL
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- APPROXIMATE UNDERGROUND
- WASTE ROCK PILE



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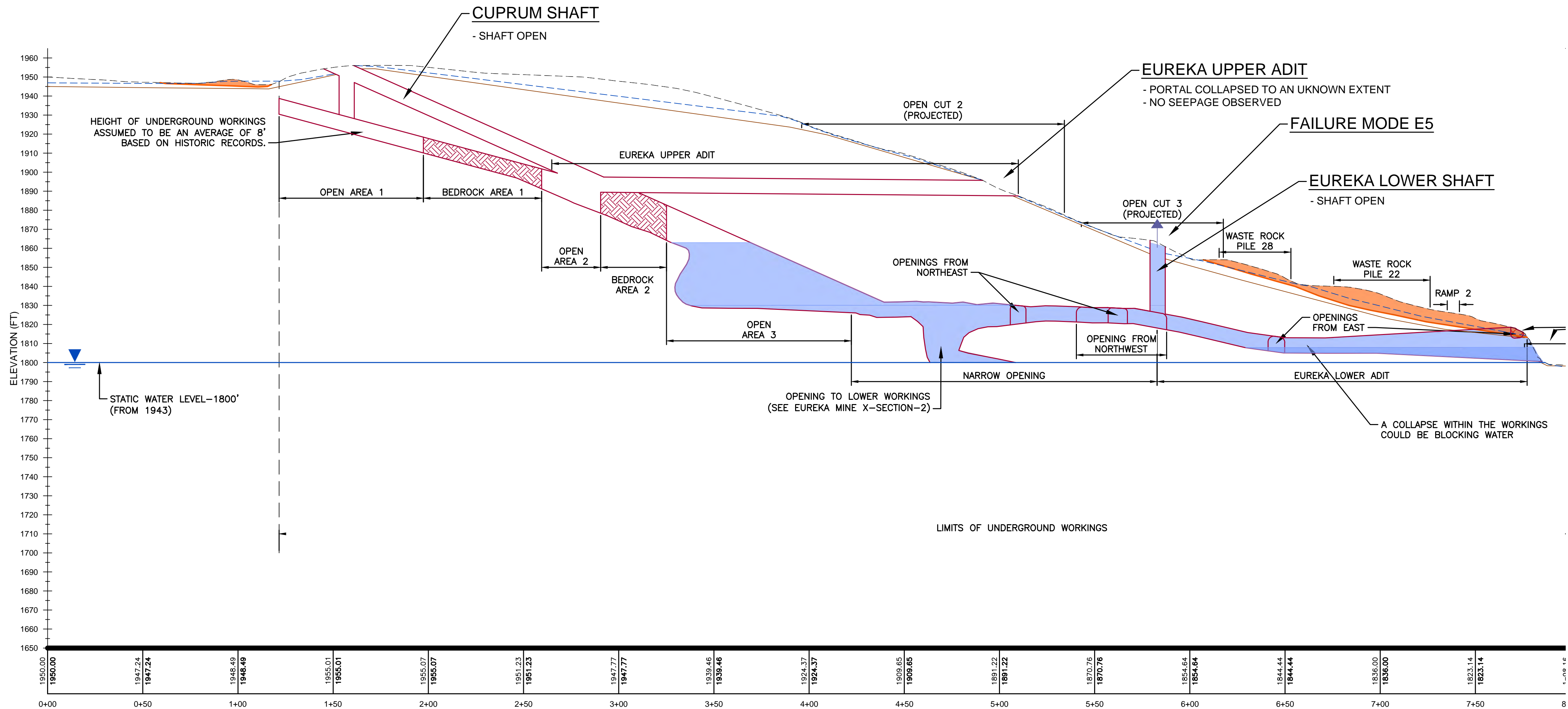
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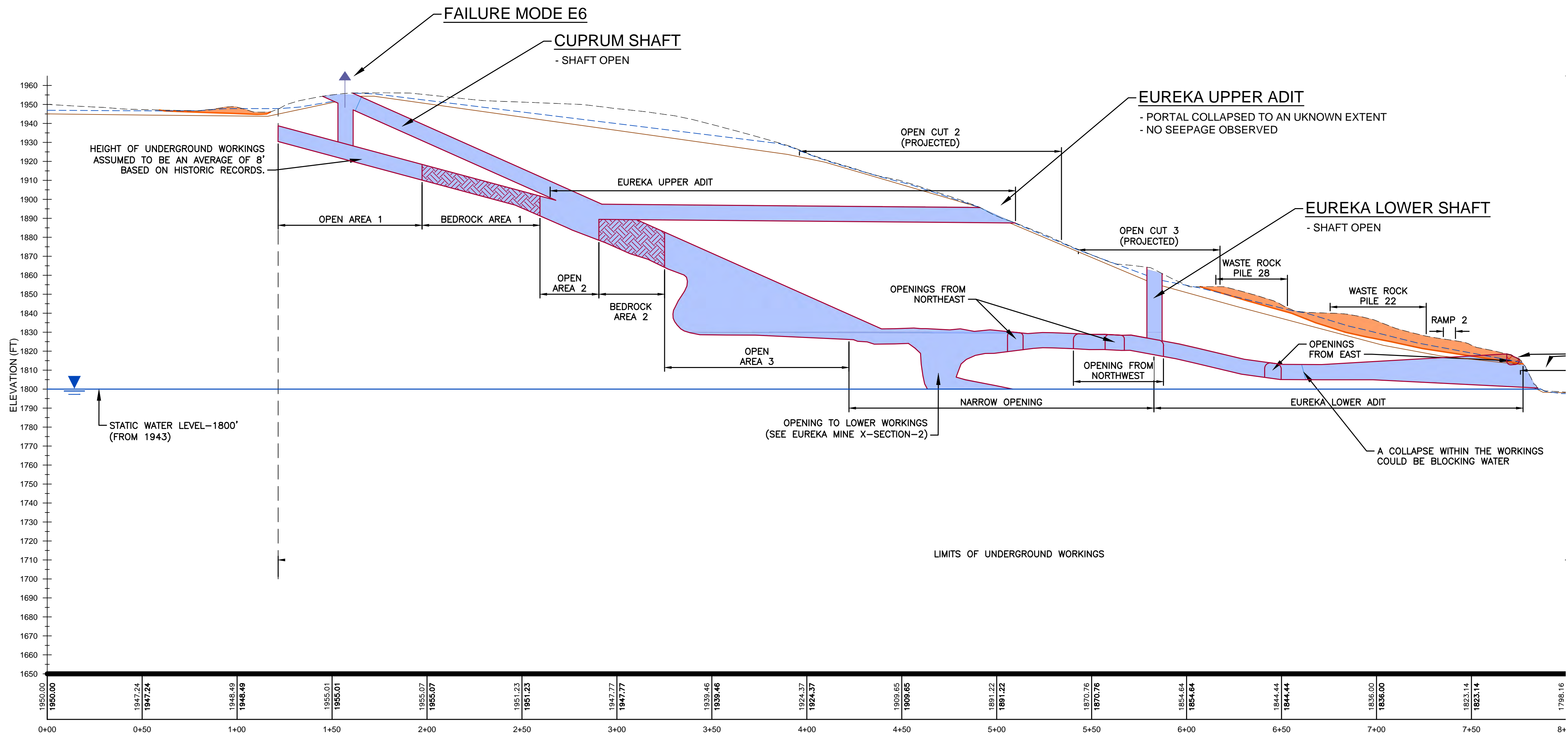
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N:\Irvine\CAD\117.00975 PIKE HILL\4. SLR CAD Files-March 2017\FIGURE.dwg-2/23/2018 3:10 PM



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LEGEND

-----	EXISTING GROUND SURFACE	-----	EXTENTS OF UNDERGROUND WORKINGS
-----	INFERRED OVERBURDEN GROUNDWATER LEVEL	-----	POTENTIAL FLOODED UNDERGROUND WORKINGS
-----	INFERRED STATIC GROUNDWATER LEVEL	-----	UNMINED BEDROCK AREA
-----	LOW RISK WATER LEVEL	-----	WASTE MATERIAL
-----	HIGH RISK WATER LEVEL	-----	FAILURE MODE EXIT PATH
-----	INFERRED BEDROCK SURFACE		

-----	APPROXIMATE L UNDERGROUND
-----	WASTE ROCK PILE

REPORT

PIKE HILL FMEA

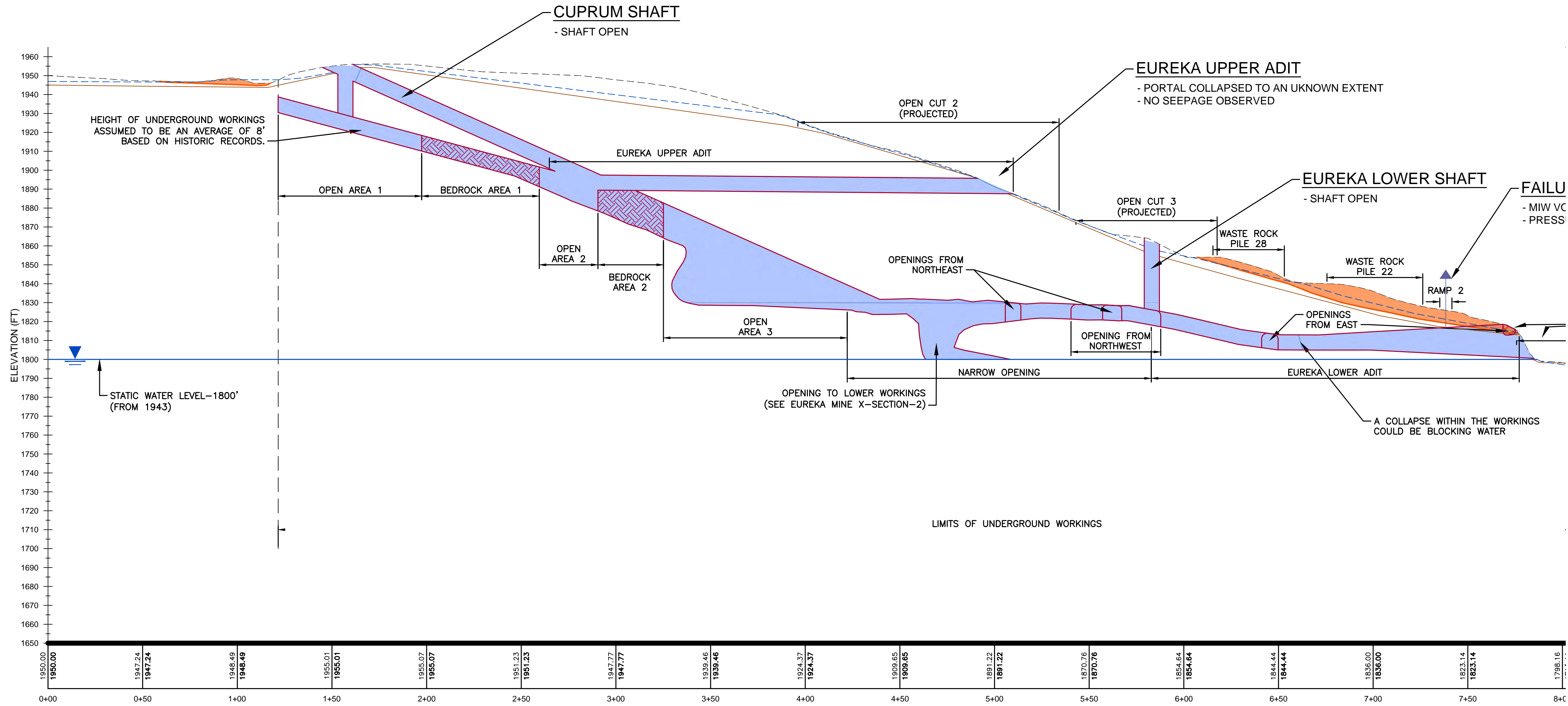
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N:\Irvine\CAD\117.00975 PIKE HILL\4. SLR CAD Files-March 2017\FIGURE.dwg-2/23/2018 3:10 PM



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- INFERRED STATIC GROUNDWATER LEVEL
- LOW RISK WATER LEVEL
- HIGH RISK WATER LEVEL
- INFERRED BEDROCK SURFACE

- EXTENTS OF UNDERGROUND WORKINGS
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- WASTE MATERIAL
- FAILURE MODE EXIT PATH

- APPROXIMATE UNDERGROUND
- WASTE ROCK

REPORT

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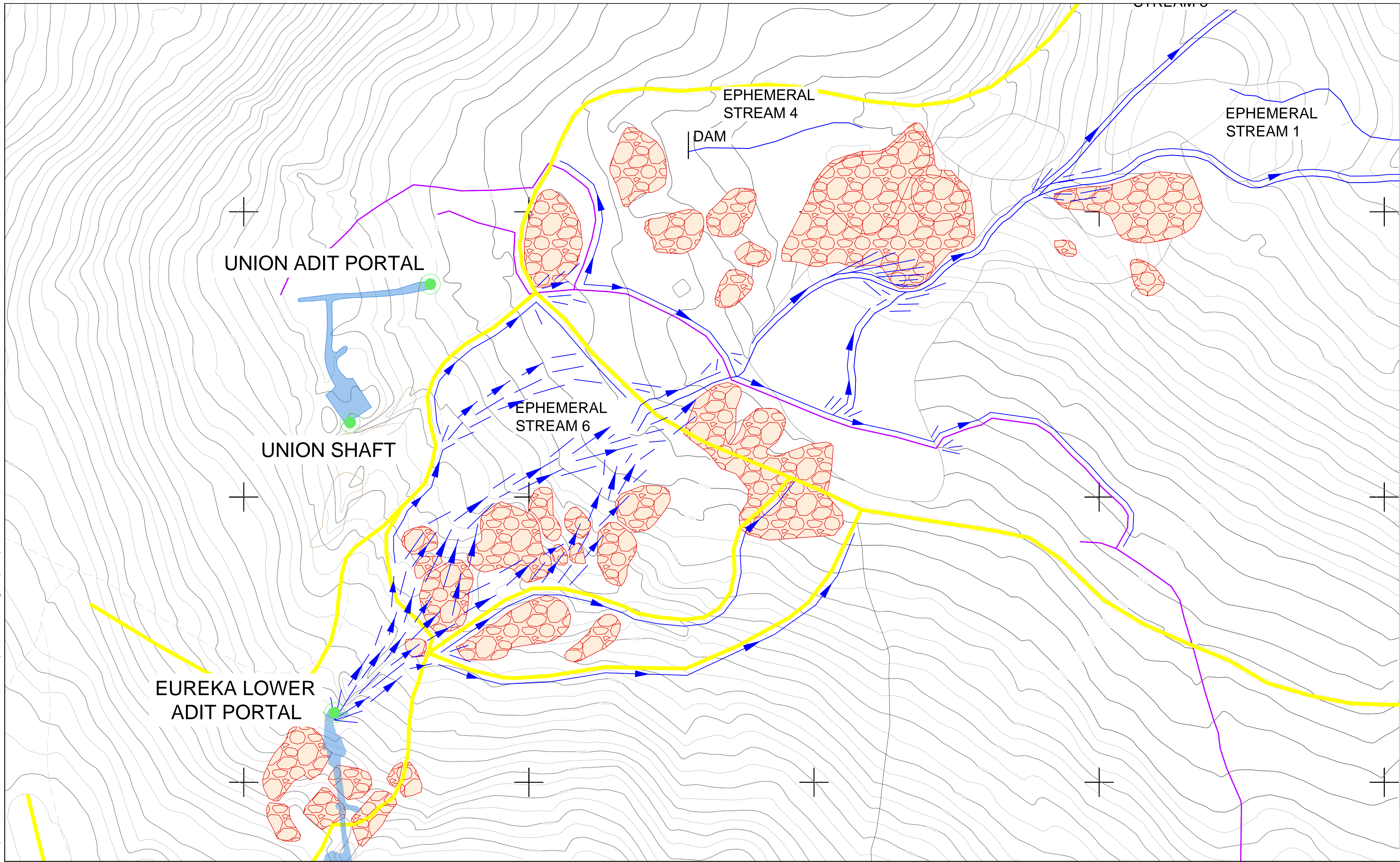
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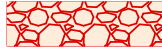






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LEGEND:

-  = WASTE ROCK PILE
-  = ROAD
-  = FAILURE MODE RELEASE POINT
-  = FAILURE MODE DISCHARGE PATH
-  = EPHEMERAL CREEK / SURFACE WATER
-  = EXISTING CHANNEL
-  = EXISTING STRUCTURE

FAILURE MODE CHARACTERISTICS:

- FAILURE MODE E1A:
- DISCHARGE VOLUME = 480,000 GALLONS
 - HEAD = 30 FT
- FAILURE MODE E1B:
- DISCHARGE VOLUME = 5,000,000 GALLONS
 - HEAD = 155 FT

Figure 6-24: PIKE HILL FMEA - SMITH RISK MATRIX WITHOUT MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300		S1b, S5, S6, S7		
	Level 2 100		S1a, S4	S8	
	Level 1 30		S2, S3		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

Figure 6-25: PIKE HILL FMEA - SMITH RISK MATRIX WITH MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300				
	Level 2 100	S6	S1b, S5, S7		
	Level 1 30	S2, S3	S1a, S4, S8		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

Figure 6-26: PIKE HILL FMEA - UNION MINE RISK MATRIX WITHOUT MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300		U1a, U1b, U6, U7, U8		
	Level 2 100		U5	U9	
	Level 1 30		U2, U3, U4		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

Figure 6-27: PIKE HILL FMEA - UNION MINE RISK MATRIX WITH MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300				
	Level 2 100	U7	U1a, U1b, U6, U8		
	Level 1 30	U2, U3, U4	U5, U9		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

Figure 6-28: PIKE HILL FMEA - EUREKA MINE RISK MATRIX WITHOUT MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300	E1b, E2b, E8	E1a		
	Level 2 100	E2a, E9	E7	E10, E11	
	Level 1 30	E4, E6	E5	E3	
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

Figure 6-29: PIKE HILL FMEA - EUREKA MINE RISK MATRIX WITH MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300	E1b, E2b, E8			
	Level 2 100	E2a, E9	E1a, E10, E11		
	Level 1 30	E4, E6	E5, E7		
	No Significant Consequence 0			E3	

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

APPENDIX A

Technical Memorandum from Charles Mettler about Pike Hill Mines Geology



Memorandum

To: Tarik Hadj-Hamou, Ph.D., P.E.

From: Charles Mettler

Date: February 2, 2017

Subject: Pike Hill Mines Geology

1. INTRODUCTION

This memorandum was prepared with the intent to evaluate the potential risks associated with anticipated remedial activities in areas of abandoned mine workings within the Pike Hill Mining District. The district consists of several mines, including the Eureka, Union and Cuprum mines plus several smaller prospects and workings. The Pike Hill copper mines are located near the town of Corinth in east-central Vermont, USA. Copper ore was extracted from the Pike Hill Mines through underground mining methods and operated from the early 1800's to the early 1900's and again sporadically during World War I and World War II. The mine is located near the northern end of what is known as the Vermont Copper Belt, a 20 mile long trend of ore deposits within Orange County, Vermont.

An understanding of risks evaluated in this study for anticipated remedial activities near the abandoned mine site included:

- The potential of underground mine workings, i.e. shafts, stopes, adits to collapse and creating dams blocking free water flow?
- Could the rocks preferentially decompose over time and resulting debris accumulate and block underground mine workings?
- Could near-surface mine workings collapse during remedial activities such drilling, earth moving (waste rock consolidation), exploratory trenching etc.?
- Could preexisting bedrock fractures reopen during the stockpile removal work allowing uncontrolled access of larger volumes of surface water into underground mine workings?

The following sources of information were used to review the geological and geotechnical environment of the Ely Mine in order to provide an answer of likelihood of the questions occurring.

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- Geochemical prospecting Investigation in the Copper Belt of Vermont, F.C. Canney. Geological Survey Bulletin 1198 – B, 1965.
- Preliminary Report, geology of the Orange County Copper District, Vermont, W.S. White and J.H. Eric, United States Department of the Interior Geological Survey, August 1944.
- Geochemical Characterization of Mine Waste, Mine Drainage, and Stream Sediments at the Pike Hill Copper Mine Superfund Site, Orange County, Vermont, 2006
- Surface-Water Hydrology and Quality at the Pike Hill Superfund Site, Corinth, Vermont, October 2004 to December 2005
- Historic/Archaeological Mapping and Testing, Pike Hill Mines Site (VT-OR-27) Corinth, Vermont, 2011

2. GEOLOGY AND GEOMORPHOLOGY

The Pike Hill Mining District is the northernmost district in the 20-mile-long, Orange County, Vermont, “copper belt” that includes the Elizabeth Mine at South Strafford and the Ely Mine at Vershire. These metallic sulfide mineral deposits are located in the Paleozoic stratigraphic units of the Connecticut Valley Trough that stretches from western Massachusetts to the Gaspee Peninsula. The bedrock underlying Orange County consists of Silurian and early Devonian meta-sediments with interspersed meta-volcanics and igneous intrusives (Doll et al. 1961). These rocks were subjected to at least three stages of intense folding and metamorphism during the early Devonian Acadian (400 million years) orogeny. Rock units typically dip steeply to the east, and become progressively younger from west to east. The Pike Hill Mines orebody is hosted by the Waits River Formation, which consists largely of metamorphosed calcareous units including pelites, minor quartzose meta-limestone and meta-dolostone, and sparse calcite marble.

The seafloor hydrothermal metallic sulfide ore deposits have been further classified into subgroups according to their original depositional environment. Geologists consider the Pike Hill Mines and other Orange County copper deposits to be examples of “Besshi” type massive sulfide deposit, which were deposited on the seafloor through hydrothermal venting (black smokers).

The shape and orientation of the Pike Hill Mines orebodies are typically stratiform and stratabound, that is they conform to and are bound by their host rock layers, which were deposited at the same time. During the tectonic processes that emplaced them in their current location and orientation, they were subjected to intense deformation and remobilization. The orebodies that survived this activity are typically pod-like, lenticular, or tabular in shape, steeply dipping, and often swell and pinch or form overlapping lenses. They are generally massive and fairly sharply bound by their schistose host rock.

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The three separate orebodies at the Pike Hill Mines are emplaced at the crest of a regional, north-south trending cleavage arch, and straddle the summit of Pike Hill. The two larger orebodies extend from the summit to the north, on the east flank of the hill. The Eureka Mine worked the southern of these two orebodies, and the Union Mine worked the one to the north. Both orebodies consisted of several discontinuous, vertically stacked, irregular, lensoid, elongate, approximately 175 ft long, approximately 8 ft wide sheets of massive sulfide ore that plunged approximately 30 to 35 degrees to the east. The deposits measure approximately 1,200 ft (366 m) on strike (linear extent of surface exposure) and descend to a maximum depth of 700 ft (213 m).

2.1. UNDERGROUND WORKINGS

Most of the ore was developed through open and locally apparent square-set stoping. Two principle shafts and three main adits were developed to access the ore. The Union Mine was developed by sinking a 900 feet shaft or 766 feet below the surface adit. The shaft allowed mining ore from four overlapping lenses by sinking winzes from the main ore zone.

Ore at the Cuprum mine, located near the summit of Pike Hill was accessed through an inclined shaft and a 1,000 feet long adit which was driven at a lower elevation to intercept the lower portions of the ore lens. This lower edit and associated workings became the Eureka mine.

Cross-sections drawn by White 1944, shows the Cuprum inclined shaft, part of which appears to have collapsed. The main Eureka adit appears to be still open in the 1944 cross sections, however water level is shown at an elevation of approximately 1790 feet, flooding most of the lower Eureka mine workings.

3. ENGINEERING GEOLOGICAL ASSESSMENT

A high level engineering geological assessment has been carried by SLR, based on experience of working in underground mines involving submarine, volcanogenic, massive sulfide ore deposits, analogous to the Pike Hill deposits. There is very limited geotechnical information on the conditions of the underground workings. However, geotechnical investigations carried out by URS in 2008 at the nearby Ely Mine, where Rock Quality Designation ("RQD") values were determined. A trend of low RQD values was observed to a depth of 30 ft. It was also stated that more fractures were observed in this 30 ft zone when compared to the deeper rock mass.

In contrast to most of the other deposits within the Vermont Copper Belt, the Pike Hill deposits are solely hosted within calcareous meta-sediments whereas most of the other deposits are

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hosted within sili-clastic, quartz-mica schists, coarse garnet schists and amphibolites, predominantly in the footwall and minor calcareous meta-sediments in the hangingwall section of the ore deposits. Calcareous meta-sediments display a far less pronounced anisotropic strength due to their lack of pronounced foliation, than exhibited in schistose meta-sediment.

However, carbonate-based lithologies as found at the Pike Hill Mine are far more susceptible to corrosion and degradation when exposed to low-pH waters. Karst development and solution collapse features can form over short periods of time when exposed to anticipated highly acidic waters emanating from the massive sulfide ore horizon. Anticipated rock-strength of these meta-carbonates should be in general very high, including high RQD values, except for normal near-surface weathering as expected in humid Vermont climate. Soils in area appear to be well developed with dark, organic rich thick A-horizon soils and likely releasing humic acids which could promote and accelerate weathering of the near-surface meta-carbonates.

The massive sulfide ore zones are presumed to be highly foliated and sheared, likely with minor faults which are either parallel to the foliation. Shearing is likely the main structural mechanism that separated the once continuous massive sulfide layer into three individual ore lenses or zones. The sulfide ore itself consist of very friable, weak lithologies, readily susceptible to decomposition, chemical alteration and weathering, including the release of very low-pH waters.

It is also anticipated that the rock fall will increase closer to surface due to a combination of factors such as a low stress environment, increased fracture frequency and decrease in the shear strength of the discontinuities with weathering.

4. CONCLUSIONS

Following the review of the geology and underground workings the following is concluded

- **The potential of underground mine workings, i.e. shafts, stopes, adits to collapse and creating dams blocking free water flow?**

The likelihood of mine workings collapsing is high, and has most likely already occurred, due to the very friable nature of the massive sulfide ore material. Mine workings outside of the ore zones within the meta-carbonates should be standing up very well, unless low-pH waters came in contact with the wallrock. In such areas solution collapse of carbonate wallrock is likely. The volume of material collapsing will depend also on the shape and size of the workings, larger spans will mean large volumes of collapse which have the potential to create a plug for damming of water. This is most likely the case in the upper workings within the stopes due to excavating the ore from one of both sides of the inclined shaft in blocks.

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The extent of water accumulation and possible over-pressurization of blocked water needs to be evaluated in detail.

- **Could the rocks preferentially decompose over time and resulting debris accumulation and block underground mine workings?**

The likelihood of this occurring is high. Near-surface generation of humic acids reacting with the meta-carbonates, rock-strength will deteriorate over time leading to rock failure over existing mine workings. This debris will accumulate over time and block the entrance to adits. However, freshly exposed meta-carbonate wall-rock should standup fairly well. Decomposition due to surface weathering and exposure to near-surface humic-acid bearing soils should not have a significant effect over a time period of at least 5-10 years.

- **Could near-surface mine workings collapse during remedial activities such drilling, earth moving (waste rock consolidation), exploratory trenching etc.**

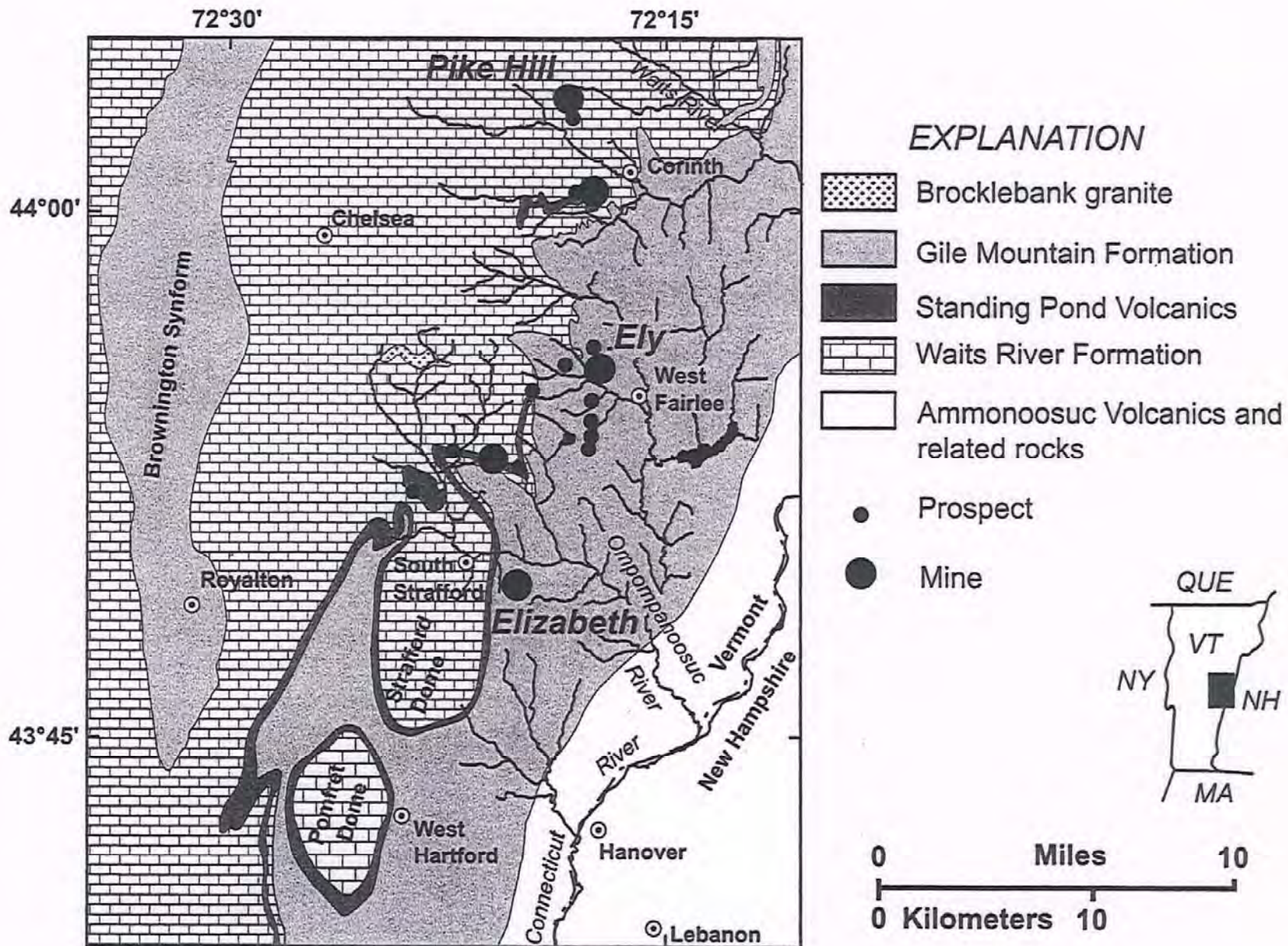
Remedial activities conducted in areas not underlain by mine workings, the likelihood of collapse is low to moderate. Anticipate rock strength of the meta-carbonates is considered high and only near-surface karst development may pose a moderate risk.

If remedial activities are planned in areas above the old mine workings the risk can be considered high. Collapse of the mine workings has likely already occurred and a stoping upward process of collapsed material moving downward would make activities in these areas quite risky.

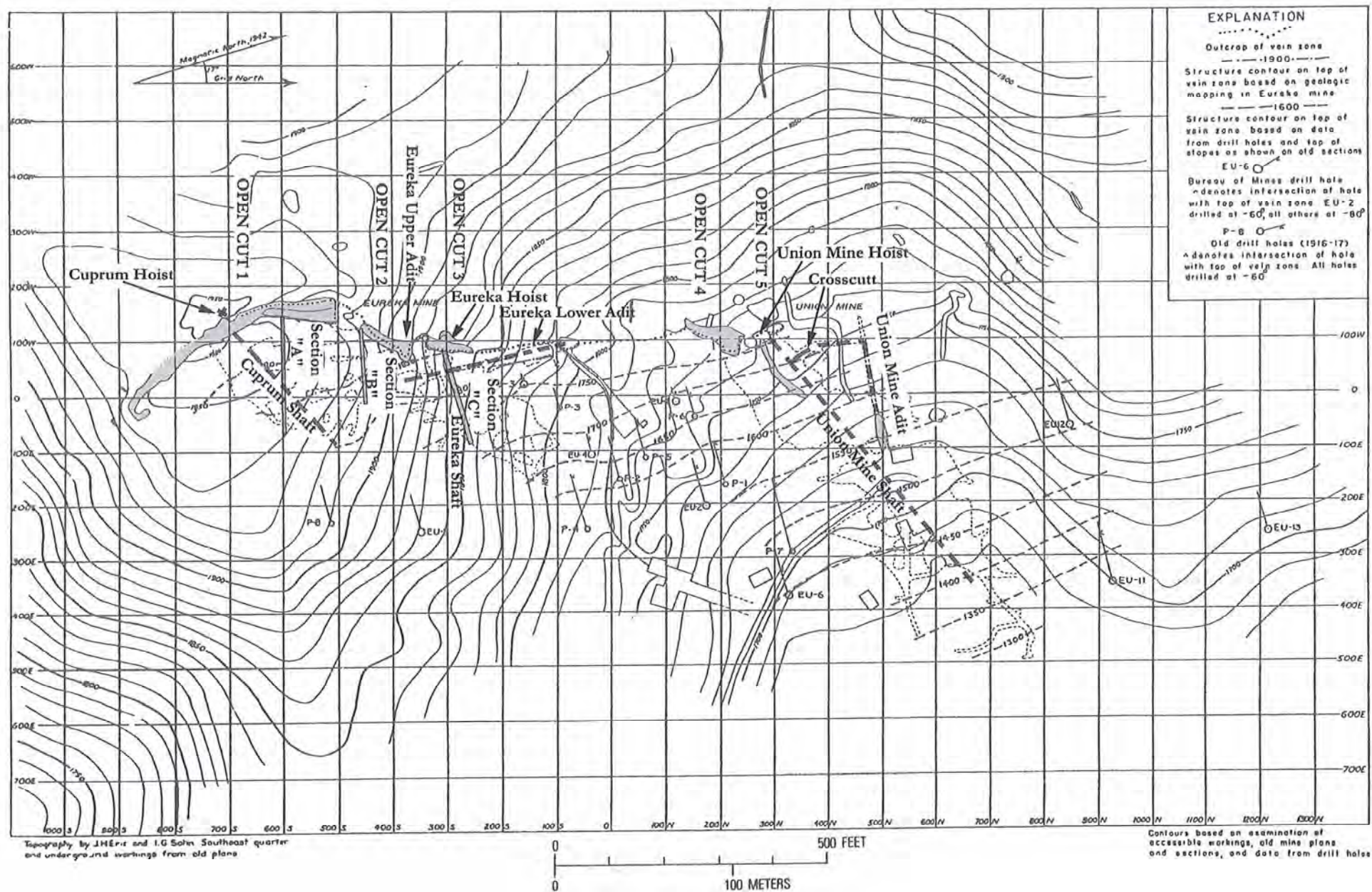
It is recommended to avoid activities in areas above the old mine workings until detailed geophysical surveys can delineate areas of potential surface breaking collapse.

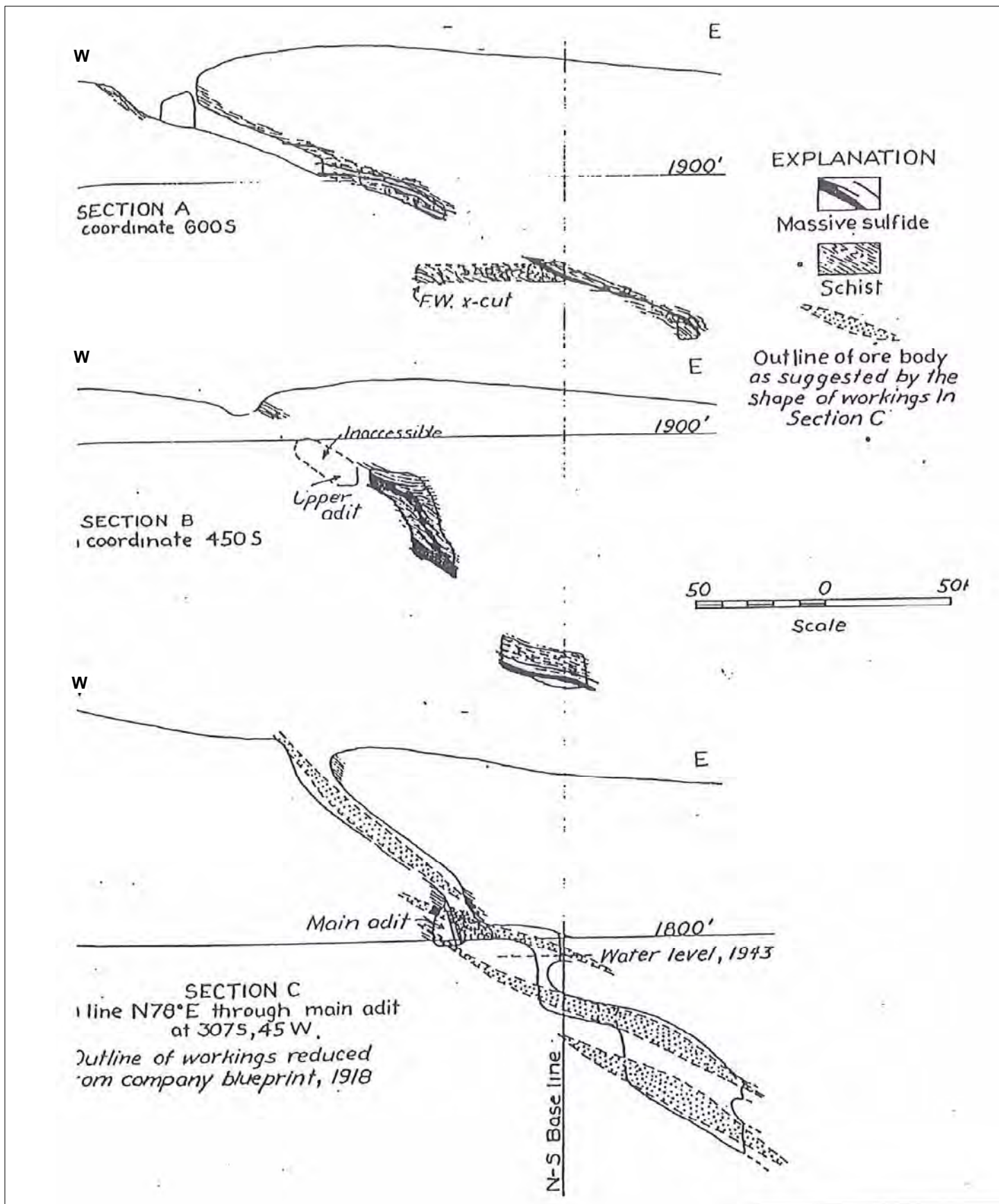
- **Could preexisting bedrock fractures reopen during the stockpile removal work allowing uncontrolled access of larger volumes of surface water into underground mine workings?**

There is a possibility of this occurring, especially in areas where upward stoping of collapsed underground working has occurred, providing channel ways of surface runoff to greater depths. Further work would be required to quantify the risk of this scenario.



Source: Historic/Archaeological Mapping and Testing, Pike Hill Mines Site (VT-OR-27) Corinth, Vermont





APPENDIX B

Pike Hill Mines FMEA Calculations

MINE	N°	FAILURE MODE	INDUCED	DATA NEED	Figure°
Smith Hill	S1a	Blow-out with violent discharge of the Smith Adit due to rising pressure/water levels behind blockage in the Smith Adit and water levels at the Low Risk Level (1657 ft amsl)	NO	Water Levels	2
	S1b	Blow-out with violent discharge of the Smith Adit due to rising pressure/water levels behind blockage in the Smith Adit and water levels at the High Risk Level (1670 ft amsl)	NO	Water Levels	3
	S2	Slow discharge from the Smith Adit due to rising water levels behind partial blockage in the Smith Adit	NO	Water Levels	4
	S3	Slow discharge from the Smith Shaft due to rising water levels behind full blockage in the Smith Adit	NO	Water Levels	5
	S4	Any noninduced surface slope failure resulting in blockage of adit	NO	None	-
	S5	Discharge or blow-out of the Smith Adit due to excavation of debris/waste in front of adit portal and water levels above the Safe Level (1649 ft amsl)	YES	Water Levels	-
	S6	Artesian discharge from underground workings due to investigative drilling into the underground workings and water levels above drilling elevation	YES	Water Levels	6
	S7	Equipment induced collapse of adit hanging wall	YES	Geology, Depth of Adit Hanging Wall	-
	S8	Any investigation induced surface slope failure resulting in blockage of adit or shaft	YES	None	-

Notes:

- Assumed static water level of 1610 ft amsl from description of mine flooding in PAL, 2011 page 188

MINE	N°	FAILURE MODE	INDUCED	DATA NEED	Figure°
Union Mine	U1a	Blow-out with violent discharge of the Union Adit due to rising pressure/water levels behind blockage in the Union Adit and water levels at the Low Risk Level (1730 ft amsl)	NO	Water Levels	8
	U1b	Blow-out with violent discharge of the Union Adit due to rising pressure/water levels behind blockage in the Union Adit and water levels at the High Risk Level (1760 ft amsl)	NO	Water Levels	9
	U2	Slow discharge from the Union Adit due to rising water levels behind partial blockage in the Union Adit	NO	Water Levels	10
	U3	Slow discharge from the Union Shaft due to rising water levels behind full blockage in the Union Adit	NO	Water Levels	11
	U4	Slow discharge from Open Cut due to rising water levels behind full blockage in the Union Adit	NO	Water Levels	12
	U5	Any noninduced surface slope failure resulting in blockage of adit	NO	None	-
	U6	Discharge or blow-out of the Union Adit due to excavation of debris/waste in front of adit portal and water levels above the Safe Level (1720 ft amsl)	YES	Water Levels	-
	U7	Artesian discharge from underground workings due to investigative drilling into the underground workings and water levels above drilling elevation	YES	Water Levels	13
	U8	Equipment induced collapse of adit hanging wall	YES	Geology, Depth of Adit Hanging Wall	-
	U9	Any investigation induced surface slope failure resulting in blockage of adit or shaft	YES	Water Levels	-

Notes:

- Assumed static water level of 1723 ft amsl from seepage/water pooling at Union Adit

MINE	N°	FAILURE MODE	INDUCED	DATA NEED	Figure°
Eureka Mine	E1a	Blow-out with violent discharge of the Eureka Lower Adit due to rising pressure/water levels behind blockage in the Eureka Lower Adit and water levels at the Eureka Lower Adit Low Risk Level (1830 ft amsl)	NO	Water Levels	15
	E1b	Blow-out with violent discharge of the Eureka Lower Adit due to rising pressure/water levels behind blockage in the Eureka Lower Adit, Eureka Lower Shaft, and Eureka Upper Adit and water levels at the Eureka Lower Adit High Risk Level (1955 ft amsl)	NO	Water Levels	16
	E2a	Blow-out with violent discharge of the Eureka Upper Adit due to rising pressure/water levels behind blockage in the Eureka Upper Adit and water levels at the Eureka Upper Adit Low Risk Level (1900 ft amsl)	NO	Water Levels	17
	E2b	Blow-out with violent discharge of the Eureka Upper Adit due to rising pressure/water levels behind blockage in the Eureka Lower Adit, Eureka Upper Adit, Eureka Lower Shaft, and Eureka Upper Adit and water levels at the Eureka Upper Adit High Risk Level (1955 ft amsl)	NO	Water Levels	18
	E3	Slow discharge from the Eureka Lower Adit due to rising water levels behind partial blockage in the Eureka Lower Adit	NO	Water Levels	19
	E4	Slow discharge from the Eureka Upper Adit due to rising water levels behind full blockage in the Eureka Lower Adit and partial blockage in the Eureka Upper Adit	NO	Water Levels	20
	E5	Slow discharge from the Eureka Lower Shaft due to rising water levels behind full blockage in the Eureka Lower Adit	NO	Water Levels	21
	E6	Slow discharge from the Cuprum Shaft due to rising water levels behind full blockages in Eureka Upper Adit, Eureka Lower Shaft, and Eureka Lower Adit	NO	Water Levels	22
	E7	Any noninduced surface slope failure resulting in blockage of adit	NO	None	-
	E8	Discharge or blow-out of the Eureka Upper Adit due to excavation of debris/waste in front of adit portal and water levels above the Eureka Upper Adit Safe Level (1890 ft amsl)	YES	Water Levels	-
	E9	Artesian discharge from underground workings due to investigative drilling into the underground workings and the water level is above drilling elevation	YES	Water Levels	23
	E10	Equipment induced collapse of adit hanging wall	YES	Geology, Depth of Adit Hanging Wall	-
	E11	Any investigation induced surface slope failure resulting in blockage of adit or shaft	YES	None	-

Notes:

- Assumed static water level of 1800 ft amsl from seepage/water pooling at Eureka Lower Adit
- Assumed connectivity between Eureka Upper Adit and Eureka Lower Adit between Bedrock Area 2 based on description in PAL, 2011 page 141

PIKE HILL FMEA - UNDERGROUND WORKING DIMENSIONS AND FILL TIMES

Location	Feature Type	Feature Name	Dimensions (ft) ¹				Total Volume (ft ³)	Total Volume (gal)	Average Seepage Rate ² (gpm)	Maximum Seepage Rate ³ (gpm)	Min Time to Fill ³ (days)	Max Time to Fill ³ (days)
			Length	Width	Height	Comments / References						
Smith Hill Mine	Shaft	Smith Shaft	8	15	15	- Height calculated from intersection with known adjoining mine features - Length and Width from PAL, 2011 page 188	1,800	13,464	50	200	0.0	0.2
	Adit	Smith Adit	75	8	8	- Length from PAL, 2011 page 188 - Width and Height approximated from site photos and similar historic features	4,800	35,904	50	200	0.1	0.5
	Stope	Unnamed Stope	65	10	10	- Length calculated from intersection with Smith Adit to static water level (1610 amsl) - Width and Height approximated from similar historic features	6,500	48,620	50	200	0.2	0.7
	Cavern	Unnamed Mined Area Above Smith Shaft	-	-	8	- Area calculated from extent of underground workings shown on 2017 Nobis X-Section and Plan View of Underground Workings Extent, represents the maximum potential cavern volume above the Smith Adit - Height approximated from similar historic features	20,800	155,584	50	200	0.5	2.2
Union Mine	Shaft	Union Shaft	15	6	30	- Dimensions from PAL 2011 page 103 - Height calculated from intersection with known adjoining mine features	2,700	20,196	50	200	0.1	0.3
	Adit	Union Adit	300	8	8	- Length from PAL 2011 page 110 - Width and Height approximated from site photos and similar historic features - Adit volume based on 2017 Nobis X-Section Plan view	41,400	309,672	50	200	1.1	4.3
	Stope	Unnamed Stope	70	8	8	- Width and Height from PAL 2011 page 103 - Length calculated from 2017 Nobis X-Section and Plan View of Underground Workings Extent (length of stope above Union Adit)	4,480	33,510	50	200	0.1	0.5
Eureka Mine	Shaft	Cuprum Shaft	135	8	8	- Length calculated from 2017 Nobis X-Section and Plan View of Underground Workings Extent (length of shaft to intersection with Open Area 2) - Length and Width approximated from site photos and similar historic features	8,640	64,627	50	200	0.2	0.9
		Eureka Lower Shaft	8	15	40	- Height calculated from intersection with known adjoining mine features - Length and Width approximated from site photos and similar historic features	4,800	35,904	50	200	0.1	0.5
	Adit	Eureka Upper Adit	112	8	8	- Length 112 ft from PAL, 2011 page 141 - Width and Height approximated from site photos and similar historic features	7,168	53,617	50	200	0.2	0.7
		Eureka Lower Adit	1000	8	8	- Length 500-1000 ft from PAL, 2011 page 141 (used conservative estimate of 1000 ft to account for unknown extent and dimensions of caverns/openings at Eureka Lower Adit elevation) - Width and Height approximated from site photos and similar historic features	64,000	478,720	50	200	1.7	6.6
	Cavern	Open Area 1	-	-	8	- Area calculated from extent of underground workings shown on 2017 Nobis X-Section and Plan View of Underground Workings Extent, represents the maximum potential cavern volume of Open Area 1 - Height approximated from similar historic features	178,400	1,334,432	50	200	4.6	18.5
		Open Area 2	-	-	8	- Area calculated from extent of underground workings shown on 2017 Nobis X-Section and Plan View of Underground Workings Extent, represents the maximum potential cavern volume of Open Area 2 - Height approximated from similar historic features	55,920	418,282	50	200	1.5	5.8
		Open Area Below Bedrock Area 2	-	-	25	- Dimensions calculated from 2017 Nobis X-Section and Plan View of Underground Workings Extent	350,000	2,618,000	50	200	9.1	36.4
		Opening to Lower Workings	8	25	30	- Width and Height calculated from 2017 Nobis X-Section and Plan View of Underground Workings Extent (height of cavern to intersection with static water level at 1800 ft amsl) - Length approximated from similar historic features	6,000	44,880	50	200	0.2	0.6

Notes:

= dimensions approximated from site photos and/or similar historic mine features

= dimensions calculated utilizing other known dimensions, locations, strikes

1. Dimensions from PAL, 2011 and approximated from mine drawings when dimensions not given.

2. Minimum and Maximum equilibrium recharge rates are the composite averages of the minimum and maximum values from neighboring Elizabeth/Ely Copper Mines

3. Time to fill = Total Volume/Discharge Rate, assuming approximate mine pool elevations of 1610, 1720, and 1800 for Smith, Union, and Eureka Mines, respectively (PAL, 2011)

PIKE HILL FMEA - BLOW-OUT CHARACTERIZATIONS

Blow-out Failure Mode Characterization						
Mine	Failure Mode Number	Volume of Water Blown-out (gal)	Head (ft)	Pressure (tons)	Minimum Time to Fill ¹ (days)	Maximum Time to Fill ¹ (days)
Smith Hill	S1a	35,904	8	16	0.3	1.2
	S1b	204,952	20	40	0.9	3.5
Union Mine	U1a	309,672	10	20	1.1	4.3
	U1b	363,378	40	80	1.3	5.0
Eureka Mine	E1a	478,720	30	60	1.8	7.3
	E1b	5,003,581	155	310	17.5	70.1
	E2a	471,898	8	16	12.7	50.7
	E2b	1,870,957	63	126	17.5	70.1

Notes:

1. Time to fill = Total Volume/Discharge Rate, assuming approximate mine pool elevations of 1610, 1720, and 1800 for Smith, Union, and Eureka Mines, respectively (PAL, 2011)

PIKE HILL FMEA - BLOW-OUT DISCHARGE EVALUATION

Blow-Out Discharge at Portal			
Parameters	Smith	Union Mine	Eureka Mine
Adit Portal Cross Sectional Area (ft ²)	64	64	64
Bernoulli's Orifice Discharge Coefficient	0.75	0.75	0.75
Max Discharge Volume (ft ³)	27,400	48,580	64,000
Maximum Blow-Out Discharge at Portal ¹ (ft ³ /s)	1,723	2,436	2,110

Notes:

1 - Blow-out discharge calculated using Bernoulli's flow through an orifice

Blow-Out Discharge in Ephemeral Streams			
Parameters	Smith	Union Min	Eureka Mine
Failure Mode Release Elevation (ft amsl)	1650	1720	1800
Site Exit Elevation ¹ (ft amsl)	1465	1485	1485
Average Slope (%)	24.5%	14.0%	15.7%
Streambed Width ² (ft)	3	3	3
Manning's Coefficient of Roughness ³	0.06	0.06	0.06
Cross Sectional Stream Area ⁴ (ft ²)	5	5	5
Hydraulic Radius	0.3	0.3	0.3
Maximum Blow-Out Flow in Ephemeral Streams ⁵ (ft ³ /sec)	20.3	15.3	16.2

Notes:

1 - Site exit point equals confluence of ephemeral site streams with off-site downstream water bodies

2 - Assumed streambed width of 3 ft based on topography and site photos

3 - Manning's coefficient of roughness for 'natural channels, poor condition' utilized

4 - Cross sectional stream area calculated assuming trapezoidal stream with streambed width of 3 ft and 1:2 slopes with 1 ft depth

5 - Maximum blow-out flow in ephemeral streams calculated using Manning's Equation

Blow-Out Discharge Across Site			
Parameters	Smith	Union Min	Eureka Mine
Site Curve Number ¹	70	70	70
Downstream Area to Site Exit ² (ft ²)	408,341	1,073,559	1,252,987
Slope of Downstream Area (%)	24.5%	14.0%	15.7%
Distance to Site Exit (ft)	750	1680	2010
Potential Maximum Retention (inches)	4.3	4.3	4.3
Initial Abstraction Excluding Interception (inches)	0.7	0.7	0.7
Site Discharge from Failure Mode (inches)	0.81	0.543	0.613
Site Runoff ³ (inches)	0.0013	0.0084	0.0
Total Site Runoff Volume ³ (ft ³)	46	751	335
Time of Concentration ⁴ (min)	2.2	5.1	5.6

Notes:

1 - Curve Number for USDA Vermont; Turnbridge-Woostock-Buckland Hydrologic Soil Group C Woodlands

2 - Site exit point equals confluence of ephemeral site streams with off-site downstream water bodies

3 - Site runoff calculated using National Resources

4 - Time of concentration calculated using Kirpich Equation

PIKE HILL FMEA - RISK SCALES

Likelihood Classes and Scale		
Likelihood Class	FMEA Score	Probability of Occurrence during Phase
High (Likely)	3	>50%
Moderate (Neutral)	1	10-50%
Low (Unlikely)	0.3	0-10%
Ruled Out	0	0%

Consequence Categories and Scale		
Consequence Category	FMEA Score	Consequence Description
Level 3	300	Economic impacts to the downstream population (loss of road use and property damage); water quality within site and downstream in ephemeral streams and other surface waters of the Waits Watershed are adversely impacted to an extent greater than current impacts for an extended period of time. Extensive visual/aesthetic impacts. Major erosion on-site (waste rock piles) requiring substantial repair, possible extended loss of use of site access roads.
Level 2	100	No significant economic impacts to the downstream population (loss of road use or damage to property); water quality with site and downstream in ephemeral streams and other surface waters of the Waits Watershed are adversely impacted to an extent greater than current impacts for a short period of time. Extensive visual/aesthetic impacts for a short period of time. Moderate erosion on-site (waste rock piles) requiring substantial repair, possible short-term loss of use of site access roads.
Level 1	30	No significant economic impacts to the downstream population (loss of road use or damage to property); water quality within site (ephemeral streams) may experience degraded water quality for a limited period of time but no significant impacts to major surface waters of the Waits Watershed. Minor erosion of waste rock piles and access roads may occur and other repairs may be necessary.
No Significant Consequences	0	No significant economic consequences or impacts to the downstream population. Any release will be of a volume and chemistry within the range of what is currently taking place under current site conditions.

PIKE HILL FMEA - SMITH FMEA

RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
			CONSQ	PROB	FMEA		Measure*	Cost (US\$)	Failure Mode Impacts		
NON-INDUCED	S1a	Blow-out with violent discharge of the Smith Adit due to rising pressure/water levels behind blockage in the Smith Adit and water levels at the Low Risk Level (1657 ft amsl)	100	0.3	30	Blow-out of the Smith Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Smith Adit with water build up to the Low Risk Level (1657 ft amsl) will release approximately 36,000 gallons of water under 8 ft of pressure head. The released water may erode the waste rock piles, and then proceed to enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage is present. If blockage is present install and be readyoperate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0.3	9
	S1b	Blow-out with violent discharge of the Smith Adit due to rising pressure/water levels behind blockage in the Smith Adit and water levels at the High Risk Level (1670 ft amsl)	300	0.3	90	Blow-out of the Smith Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Smith Adit with water build up to the High Risk Level (1670 ft amsl) will release approximately 205,000 gallons of water under 20 ft of pressure head. The released water will damage the waste rock piles, and then proceed to enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage is present. If blockage is present install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	100	0.3	30
	S2	Slow discharge from the Smith Adit due to rising water levels behind partial blockage in the Smith Adit	30	0.3	9	Water/pressure levels rise behind blockage in the Smith Adit until water discharges through or around the blockage, to a flow large enough to potentially erode the waste rock piles or enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if flow increases or decreases (sign of potential blockage). Install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0	0
NON-INDUCED	S3	Slow discharge from the Smith Shaft due to rising water levels behind full blockage in the Smith Adit	30	0.3	9	Water/pressure levels rise behind blockage in the Smith Adit until water discharges out of the Smith Shaft, to a flow large enough to potentially erode the waste rock piles and/or enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage is present. If blockage is present install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0	0
	S4	Any noninduced surface slope failure resulting in blockage of adit	100	0.3	30	Any surface slope failure resulting in the blockage of mine features below or within the failure mode footprint, which in turn could lead to blow-outs or discharges if water accumulates per Failure Modes A1, S2, and/or S3. Additionally, debris could enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor slopes above the adit for signs of eminent failure (cracks, fissures). Monitor working water levels and outflows to notice any changes. Install and be ready operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0.3	9
INDUCED	S5	Discharge or blow-out of the Smith Adit due to excavation of debris/waste in front of adit portal and water levels above the Safe Level (1649 ft amsl)	300	0.3	90	Blow-out or discharge of the Smith Adit due to excavation will release built up pressure and water, potentially endangering anyone near the adit. Blow-out of the Smith Adit with water build up above the Safe Water Level (1649 ft amsl) could release up to 205,000 gallons of water. The released water may damage the waste rock piles, and then proceed to enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor removal activities for signs of imminent failure such as increase moisture in soil/debris, seepage, formation of fissures, and rumbling noise. Monitor working water levels and outflows to notice any changes. Install and be ready operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	100	0.3	30

PIKE HILL FMEA - SMITH FMEA

RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
			CONSQ	PROB	FMEA		Measure*	Cost (US\$)	Failure Mode Impacts		
									CONSQ	PROB	FMEA
INDUCED	S6	Artesian discharge from underground workings due to investigative drilling into the underground workings and water levels above drilling elevation	300	0.3	90	Artesian discharge from underground workings due to investigative drilling into the underground workings with water levels above the drilling elevation will release water that can potentially erode the waste rock piles before proceeding to enter the surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage is present If blockage is presnet install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	100	0	0
	S7	Equipment induced collapse of adit hanging wall	300	0.3	90	Equipment induced collapse of an adit hanging wall could result in the blockage of mine features below or within the failure mode footprint, which in turn could lead to blow-outs or discharges if water accumulates per Failure Modes S1 through S3.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage is present If blockage is present install and operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	100	0.3	30
	S8	Any investigation induced surface slope failure resulting in blockage of adit or shaft	100	1	100	Any induced surface slope failure resulting in the blockage of mine features below or within the failure mode footprint, which in turn could lead to blow-outs or discharges if water accumulates. Additionally, slope failure could endanger onsite workers and enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor surroundings moslty above adits for sign of distress (fissures, cracks,, seeps). Monitor working water levels and outflows. Install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0.3	9
AVERAGE					64	AVERAGE					14
MAXIMUM					100	MAXIMUM					30

Notes:
* = Site Investigation/Characterization activities are separate from Mitigation Measures. Site Investigation/Characterization activities are combined with Mitigation Measures in this appendix (Appendix B) to reduce the table size.

PIKE HILL FMEA - UNION MINE FMEA

RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
			CONSQ	PROB	FMEA		Measure*	Cost (US\$)	Failure Mode Impacts		
									CONSQ	PROB	FMEA
NON-INDUCED	U1a	Blow-out with violent discharge of the Union Adit due to rising pressure/water levels behind blockage in the Union Adit and water levels at the Low Risk Level (1730 ft amsl)	300	0.3	90	Blow-out of the Union Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Union Adit with water build up to the Low Risk Level (1730 ft amsl) will release approximately 310,000 gallons of water under 10 ft of pressure head. The released water will damage the waste rock piles, roads, and then proceed to enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage is present If blockage is present install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	100	0.3	30
	U1b	Blow-out with violent discharge of the Union Adit due to rising pressure/water levels behind blockage in the Union Adit and water levels at the High Risk Level (1760 ft amsl)	300	0.3	90	Blow-out of the Union Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Union Adit with water build up to the High Risk Level (1760 ft amsl) will release approximately 365,000 gallons of water under 40 ft of pressure head. The released water will damage the waste rock piles, may damage the roads, and then proceed to enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage is present If blockage is present, install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	100	0.3	30
	U2	Slow discharge from the Union Adit due to rising water levels behind partial blockage in the Union Adit	30	0.3	9	Water/pressure levels rise behind blockage in the Union Adit until water discharges through or around the blockage, to a flow large enough to potentially erode the waste rock piles, reach the roads, or enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0	0
NON-INDUCED	U3	Slow discharge from the Union Shaft due to rising water levels behind full blockage in the Union Adit	30	0.3	9	Water/pressure levels rise behind blockage in the Union Adit until water discharges out of the Union Shaft and flows over the waste rock piles, reach the roads, and/or enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage is present If blockage is present install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0	0
	U4	Slow discharge from Open Cut due to rising water levels behind full blockage in the Union Adit	30	0.3	9	Water/pressure levels rise behind blockage in the Union Adit until water discharges out of the Open Cut and flows over the waste rock piles, reach the roads, and/or enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage is present If blockage is present install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0	0
	U5	Any noninduced surface slope failure resulting in blockage of adit	100	0.3	30	Any surface slope failure resulting in the blockage of mine features below, which in turn could lead to blow-outs or discharges if water accumulates per Failure Modes U1 through U3. Additionally, slope failure material could enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: moitor slopes above the adit for sign of diostress (cracks, fissures, seeps). Monitor working water levels and outflows. Install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0.3	9

PIKE HILL FMEA - UNION MINE FMEA

RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
			CONSQ	PROB	FMEA		Measure*	Cost (US\$)	Failure Mode Impacts		
									CONSQ	PROB	FMEA
INDUCED	U6	Discharge or blow-out of the Union Adit due to excavation of debris/waste in front of adit portal and water levels above the Safe Level (1720 ft amsl)	300	0.3	90	Blow-out or discharge of the Union Adit due to excavation will release built up pressure and water, potentially endangering anyone near the adit. Blow-out of the Union Adit with water build up above the Safe Water Level (1720 ft amsl) could release up to 365,000 gallons of water The released water will damage the waste rock piles, roads, and then proceed to enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor removal activities for sign of distress such as increased moisture in soil/debris, fissures, cracks and rumbling noise. Monitor working water levels and outflows. Install and operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	100	0.3	30
INDUCED	U7	Artesian discharge from underground workings due to investigative drilling into the underground workings and water levels above drilling elevation	300	0.3	90	Artesian discharge from underground workings due to investigative drilling into the underground workings with water levels above the drilling elevation will release water that can potentially damage the waste rock piles or roads before proceeding to enter the surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor drilling activities for sign of artesian pressure. Monitor working water levels and outflows to determine if blockage is present If blockage is present install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	100	0	0
	U8	Equipment induced collapse of adit hanging wall	300	0.3	90	Equipment induced collapse of an adit hanging wall could result in the blockage of mine features below or within the failure mode footprint, which in turn could lead to blow-outs or discharges if water accumulates per Failure Modes U1 through U3.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	100	0.3	30
	U9	Any investigation induced surface slope failure resulting in blockage of adit or shaft	100	1	100	Any induced surface slope failure resulting in the blockage of mine features below or within the failure mode footprint, which in turn could lead to blow-outs or discharges if water accumulates per Failure Modes U1 through U3. Additionally, slope failure could endanger onsite workers and debris from the failed mass enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0.3	9
AVERAGE					57	AVERAGE					12
MAXIMUM					100	MAXIMUM					30

Notes:

* = Site Investigation/Characterization activities are separate from Mitigation Measures. Site Investigation/Characterization activities are combined with Mitigation Measures in this appendix (Appendix B) to reduce the table size.

PIKE HILL FMEA - EUREKA MINE FMEA

RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
			CONSQ	PROB	FMEA		Measure*	Cost (US\$)	Failure Mode Impacts		
									CONSQ	PROB	FMEA
NON-INDUCED	E1a	Blow-out with violent discharge of the Eureka Lower Adit due to rising pressure/water levels behind blockage in the Eureka Lower Adit and water levels at the Eureka Lower Adit Low Risk Level (1830 ft amsl)	300	0.3	90	Blow-out of the Eureka Lower Adit Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Eureka Lower Adit with water build up to the Eureka Lower Adit Low Risk Level (1830 ft amsl) will release approximately 480,000 gallons of water under 30ft of pressure head. The released water will damage the waste rock piles, flow on the roads, and then proceed to enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activities should be sequenced from the highest to lowest elevations with respect to the adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels namely in the Eureka Lower Shaft and outflows to determine if blockage is present. If blockage is present install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	100	0.3	30
	E1b	Blow-out with violent discharge of the Eureka Lower Adit due to rising pressure/water levels behind blockage in the Eureka Lower Adit, Eureka Lower Shaft, and Eureka Upper Adit and water levels at the Eureka Lower Adit High Risk Level (1955 ft amsl)	300	0	0	Blow-out of the Eureka Lower Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Eureka Lower Adit with water build up to the Eureka Upper/Lower Adit High Risk Level (1955 ft amsl) will release approximately 5,000,000 gallons of water under 155 ft of pressure head. The released water will damage the waste rock piles, roads, and then proceed to enter surface waters of the Waits Watershed.	None needed.		300	0	0
	E2a	Blow-out with violent discharge of the Eureka Upper Adit due to rising pressure/water levels behind blockage in the Eureka Upper Adit and water levels at the Eureka Upper Adit Low Risk Level (1900 ft amsl)	100	0	0	Blow-out of the Eureka Upper Adit Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Eureka Upper Adit with water build up to the Eureka Upper Adit Low Risk Level (1900 ft amsl) will release approximately 475,000 gallons of water. The released water will erode the waste rock piles, reach the roads, and then proceed to enter surface waters of the Waits Watershed.	None needed.		100	0	0
NON-INDUCED	E2b	Blow-out with violent discharge of the Eureka Upper Adit due to rising pressure/water levels behind blockage in the Eureka Lower Adit, Eureka Upper Adit, Eureka Lower Shaft, and Eureka Upper Adit and water levels at the Eureka Upper Adit High Risk Level (1955 ft amsl)	300	0		Blow-out of the Eureka Upper Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Eureka Upper Adit with water build up to the Eureka Upper/Lower Adit High Risk Level (1955 ft amsl) will release approximately 1,875,000 gallons of water under 63 ft of pressure head. The released water will damage the waste rock piles, roads, and then proceed to enter surface waters of the Waits Watershed.	None needed.		300	0	0
	E3	Slow discharge from the Eureka Lower Adit due to rising water levels behind partial blockage in the Eureka Lower Adit	30	1	30	Water/pressure levels rise behind blockage in the Eureka Lower Adit until water discharges around or through the blockage, to a flow large enough to erode the waste rock piles, reach the roads, or enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor working water levels and outflows to determine if blockage is present. If blockage is present install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	0	1	0
	E4	Slow discharge from the Eureka Upper Adit due to rising water levels behind full blockage in the Eureka Lower Adit and partial blockage in the Eureka Upper Adit	30	0	0	Water/pressure levels rise behind blockage in the Eureka Upper Adit until water discharges through or around the blockage, and flows over the waste rock piles, roads, or enter surface waters of the Waits Watershed.	None needed.		30	0	0
	E5	Slow discharge from the Eureka Lower Shaft due to rising water levels behind full blockage in the Eureka Lower Adit	30	0.3	9	Water/pressure levels rise behind blockage in the Eureka Lower Adit until water discharges out of the Eureka Lower Shaft and flows over the waste rock piles, may reach the roads, or enter surface waters of the Waits Watershed.	None needed.		30	0.3	9
	E6	Slow discharge from the Cuprum Shaft due to rising water levels behind full blockages in Eureka Upper Adit, Eureka Lower Shaft, and Eureka Lower Adit	30	0	0	Water/pressure levels rise behind blockages until water discharges out of the Cuprum Shaft. Water may flow over the waste rock piles onto the roads and/or enter surface waters of the Waits Watershed.	None needed.		30	0	0
NON-INDUCED	E7	Any noninduced surface slope failure resulting in blockage of adit	100	0.3	30	Any surface slope failure resulting in the blockage of mine features, which in turn could lead to blow-outs or discharges if water accumulates per Failrue Modes E1 through E6. Additionally, slope failure debris could enter surface waters of the Waits Watershed.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND; Monitoring and Dewatering Plan: Monitor are above adit for signs of distress and/or imminent failures such as cracks, fissures and seeps. Monitor working water levels and outflows to determine if blockages are present. If blockages are present, install and be ready to operate a dewatering system connected to a treatment system, as necessary.	100K - <1M	30	0.3	9

PIKE HILL FMEA - EUREKA MINE FMEA

RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
			CONSQ	PROB	FMEA		Measure*	Cost (US\$)	Failure Mode Impacts		
									CONSQ	PROB	FMEA
INDUCED	E8	Discharge or blow-out of the Eureka Upper Adit due to excavation of debris/waste in front of adit portal and water levels above the Eureka Upper Adit Safe Level (1890 ft amsl)	300	0	0	Blow-out or discharge of any adit due to excavation will release built up pressure and water, potentially endangering anyone near the adit. Blow-out of an adit with water build up above the Safe Water Level (1800 ft amsl) could release up to 5,000,000 gallons of water under a pressure head of 155 ft if the blockage conditions of Failure Mode E1b are present. The released water would damage the waste rock piles, roads, and then proceed to enter surface waters of the Waits Watershed.	None needed.		300	0	0
	E9	Artesian discharge from underground workings due to investigative drilling into the underground workings and the water level is above drilling elevation	300	0	0	Artesian discharge from underground workings due to investigative drilling into the underground workings with water levels above the drilling elevation will release water that can potentially erode the waste rock piles or roads before proceeding to enter the surface waters of the Waits Watershed. Depending upon the blockage conditions in the underground workings, the artesian head could be as high as 155ft in the Eureka Lower Adit	None needed.		300	0	0
INDUCED	E10	Equipment induced collapse of adit hanging wall	100	1	100	Equipment induced collapse of an adit hanging wall could result in the blockage of mine features below or within the failure mode footprint, which in turn could lead to blow-outs or discharges if water accumulates per one of the Failrue Modes E1 through E6.	Site Investigation / Characterization: Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. Impliment a heavy equipment work restriction zone based on expected ground pressures and forces; utilize low ground pressure equipment for earthwork and drilling; prepare activity-specific FMEA to evaluate the specific activities in detail.	100K - <1M	100	0.3	30
	E11	Any investigation induced surface slope failure resulting in blockage of adit or shaft	100	1	100	Any induced surface slope failure resulting in the blockage of mine features below, which in turn could lead to blow-outs or discharges if water accumulates per one of Failreu Modes E1 through E6. Additionally, slope failure could endanger onsite workers and enter surface waters of the Waits Watershed. Debris form the sloepfailreu mass could also enter the Waits Watershed			100	0.3	30
AVERAGE					22	AVERAGE					7
MAXIMUM					100	MAXIMUM					30

Notes: * = Site Investigation/Characterization activities are separate from Mitigation Measures. Site Investigation/Characterization activities are combined with Mitigation Measures in this appendix (Appendix B) to reduce the table size.

PIKE HILL FMEA - RISK CHARACTERIZATION MATRIX

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300				
	Level 2 100				
	Level 1 30				
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

PIKE HILL FMEA - SMITH RISK MATRIX WITHOUT MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300		S1b, S5, S6, S7		
	Level 2 100		S1a, S4	S8	
	Level 1 30		S2, S3		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

PIKE HILL FMEA - SMITH RISK MATRIX WITH MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300				
	Level 2 100	S6	S1b, S5, S7		
	Level 1 30	S2, S3	S1a, S4, S8		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

PIKE HILL FMEA - UNION MINE RISK MATRIX WITHOUT MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300		U1a, U1b, U6, U7, U8		
	Level 2 100		U5	U9	
	Level 1 30		U2, U3, U4		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

PIKE HILL FMEA - UNION MINE RISK MATRIX WITH MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300				
	Level 2 100	U7	U1a, U1b, U6, U8		
	Level 1 30	U2, U3, U4	U5, U9		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

PIKE HILL FMEA - EUREKA MINE RISK MATRIX WITHOUT MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300	E1b, E2b, E8	E1a		
	Level 2 100	E2a, E9	E7	E10, E11	
	Level 1 30	E4, E6	E5	E3	
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

PIKE HILL FMEA - EUREKA MINE RISK MATRIX WITH MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300	E1b, E2b, E8			
	Level 2 100	E2a, E9	E1a, E10, E11		
	Level 1 30	E4, E6	E5, E7		
	No Significant Consequence 0			E3	

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences